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THE ELEMENTS OF THE OIL-WELL-SPACING PROBLEM

A SUMMARY OF THE FACTORS INFLUENCING THE DISTANCE APART AT WHICH OIL WELLS MAY BE ECONOMICALLY SPACED

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ABSTRACT

This paper reviews the several factors which determine the spacing of wells in planning the development of oil fields to secure the maximum economic ultimate recovery of petroleum. The physical factors controlling oil drainage are given special consideration, and the limitations of our present knowledge of their influence are pointed out. The expulsive effects of gas pressure, gravity, and edgewater pressure in causing movement of oil into wells are discussed, and quantitative experimental data are produced showing the influence of pore resistance and capillarity of oil sands and viscosity and adhesion of the oil in resisting the expulsive forces. The influence of geologic structure, of the diameter of the well, and of the depth and thickness of the productive sand on the economic interval between wells is also explained. The more important economic considerations in planning the development program—particularly the interest cost of deferred production, the cost and efficiency of production, and the future selling price of petroleum—are discussed in general terms. The fallacy of using well production records as a basis for well-spacing, without supplementary study of the more fundamental variables controlling oil drainage, is pointed out. In conclusion, the author summarizes in tabular form the qualitative effect of the several variables discussed, and suggests the necessity for a thorough technical study of the factors controlling oil drainage in order that the spacing of wells may be placed on a more scientific basis.

INTRODUCTION

Determination of the distance apart at which wells must be spaced to realize the maximum profit in oil production is one of the most important problems confronting the oil producer, a problem the importance of which has been fully recognized by producers for many years, but one, nevertheless, which has not yet been satisfactorily solved. Sporadic efforts toward a solution of the problem have been made by certain government agencies such as the United States Bureau of Mines, and some useful data have been accumulated;

possibly some of the oil companies have progressed farther, but if so their results have not been published. The present paper is offered as a general outline of the well-spacing problem, in which the variables to be studied are enumerated, the present state of our knowledge concerning them briefly discussed, and a program of research proposed which should lead to a satisfactory conclusion.

When a new oil field is discovered and the early development work has proceeded to a point where certain areas are known to be productive, the owners of these proved sections are at once confronted with the necessity for determining upon a suitable development program. How many wells shall be drilled? Where shall they be located? When should they be drilled, and in what sequence? Economic considerations are uppermost in the mind of the producer in his effort to plan the development so as to realize maximum profit. The greater the number of wells, the more rapidly and completely will the oil be recovered. Obviously, as few wells as will result in recovery of the available oil should be drilled; and yet the cost of additional wells will be offset to a certain point by the interest-earning capacity of money more promptly realized through the drilling of the additional wells. The size and shape of the property and the activities of neighboring operators will influence the result. The condition of the market for petroleum and considerations of probable future price will also have a bearing. All of these considerations are distinct from the more technical factors which determine the effective radius of drainage of a well under the conditions prevailing, and which influence the percentage recovery of the available oil.

We may classify these different variables under two general headings:

Physical Factors	Economic Factors
Gas pressure	The interest cost of deferred production
Gravitational effects	The cost of production
Edgewater pressure	The selling price of oil
Porosity and texture of reservoir rock	Competitive conditions
Oil viscosity: capillarity and adhesion	Production efficiency
Influence of the diameter of the well	
Depth and thickness of the productive sand	
Influence of geologic structure	

It is apparent that the economic spacing of oil wells is dependent upon a variety of factors, some of which are exceedingly difficult of analysis and in certain cases impossible of accurate determination. Since the elements entering into the well-spacing problem are variables, it follows that their resultant will also be variable, that is, a suitable interval between wells for one set of conditions will necessarily be different from that appropriate for a different set of conditions. We can best proceed toward the solution of a problem involving a number of different variables by a critical study and quantitative evaluation of each factor. In the following discussion, it is proposed to review briefly our present knowledge concerning each factor entering into the problem of well-spacing, and to indicate wherein our understanding falls short of what is necessary to effect a complete solution. An effort will also be made to suggest methods of investigation which will close the gaps in our present knowledge and make possible a fuller understanding of the factors involved.

PHYSICAL FACTORS

The effect of gas pressure.—The pressure of natural gas dissolved and occluded within the oil is recognized as the most important of the expulsive forces which are responsible for movement of oil into the wells. Investigations have shown, in the case of flowing wells, that the oil-production decline curve displays a marked parallelism with the gas-pressure decline curve[1] (Fig. 1). Many observers have noted a certain relation between the volumes of oil and gas produced during unit time intervals. Laboratory studies have shown that the pressure resulting from natural gas provides a force of great magnitude, capable of driving crude petroleum through porous sands for hundreds of feet; and the distance which the oil may travel, or the drainage radius of the well, will vary with the pressure of the associated gas.

Recent tests made by the United States Bureau of Mines have indicated that petroleum is capable of dissolving about half of its volume of natural gas at normal atmospheric temperature and pressure. At higher pressures, according to Henry's law, the solubility

[1] C. H. Beal, "The Decline and Ultimate Production of Oil Wells," *U. S. Bureau of Mines Bulletin 177*, p. 76.

of the gas should increase in direct ratio with the pressure, so that, at say 250-pound pressure, the oil should be capable of dissolving about eight times its volume of gas; at 500 pounds, sixteen times its volume; and at 1,000 pounds, thirty-two times its volume. That is, if we had a cubic foot of oil saturated with dissolved gas under a pressure of 1,000 pounds per square inch, and reduced the pressure to atmospheric, 32 cubic feet of gas would be liberated; and if this gas were retained within the oil in occluded form, the oil would literally expand to thirty-three times its original volume. It is chiefly this

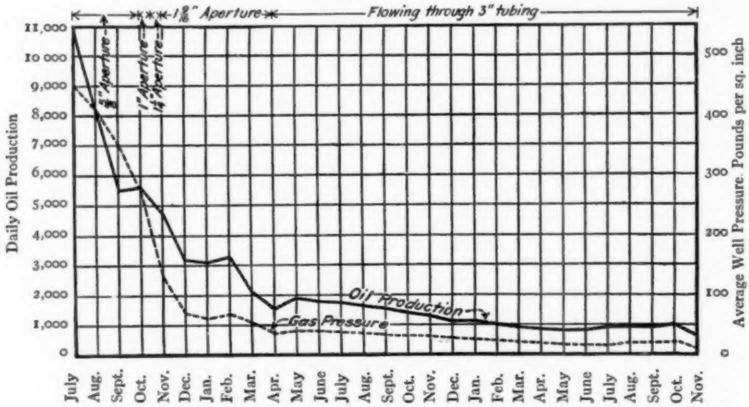

FIG. 1.—Oil-production and gas-pressure decline curves for a flowing well in the Midway-Sunset field, California. (After C. H. Beal in *U. S. Bureau of Mines Bull. 177*.)

expansive force of the dissolved and occluded gas which causes petroleum to flow from the sand into the well. In practice, however, we do not recover anything like 32/33 of the oil present in the sand; hence the present process is a wasteful one, much of the gas apparently escaping from the oil in the sand without doing useful work in moving oil.

One reason for this inefficiency may be found in the tendency of the oil to become concentrated in the lower horizons of the strata to which it has access. When a part of the oil has been forced out of the sand, the remainder settles to the bottom of the containing

stratum, leaving a layer of drained oil sand just beneath the cap rock (Fig. 2). Gas finds its path of least resistance through this drained portion of the reservoir rock, escaping from the oil and flowing to the well outlets from remote positions.

As gas is an important factor in its influence on oil drainage, in determining the appropriate spacing of wells in a given locality, studies must be made of the available pressures and the rate at which the pressure is declining. Such information may be obtained by a

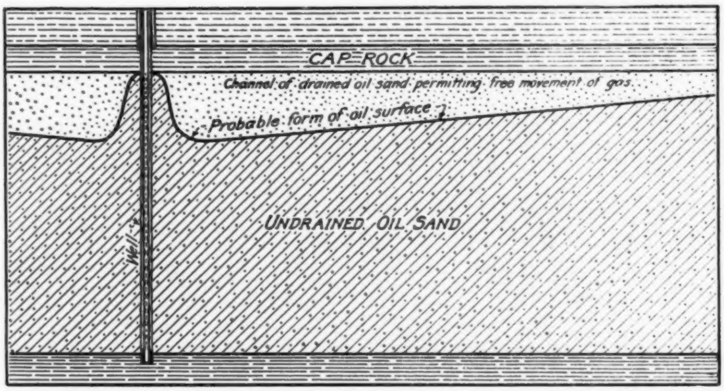

FIG. 2.—Sketch illustrating drainage of gas through channel beneath cap rock from which oil has settled by gravity. The well is assumed to be flowing.

study of static fluid levels in wells at different periods, or by making closed pressure tests at regular intervals of time. Such investigations should contemplate the possibility of developing methods for improving the efficiency of gas expulsion, such as the maintenance of back pressure on wells,[1] pumping gas back into the sands,[2] or admitting high-pressure gas to partially exhausted sands from an extraneous source.[3]

[1] T. E. Swigart, "Experiments on Back Pressure on Oil Wells," *Reports of Investigations, U. S. Bureau of Mines, No. 2420*, December, 1922.

[2] The writer has recently designed a pump for extracting gas from the oil in the well and pumping it back into the space above the oil surface in the productive sand, thus restoring and maintaining the original gas pressure.

[3] M. J. Kirwin, "Effects of Extraneous Gas on the Production of Oil Wells in the Lyons-Quinn Field of Oklahoma," *U. S. Bureau of Mines Reports of Investigations, No. 2612*, June, 1924.

The manner in which gas accomplishes this expulsion of oil from the sand should be studied. Is its action entirely due to expansion from within as suggested above, or is it partly the result of expansion of large bodies of free gas trapped at favorable points in the reservoir rock? If the former, how do bubbles of gas move through the minute openings between sand grains, and just how do they accomplish movement of the associated oil? To what extent does diffusion make possible the translation of natural gas in solution through petroleum, and over what distances and how rapidly is such diffusion accomplished?

Gravitational effects in oil drainage.—In addition to gas pressure, gravity provides an ever present force which has an important influence upon the flow of oil into a well. As a result of gravitational force, the pressure within a body of liquid increases directly with depth—a force which is always equivalent to the weight of the superimposed body of fluid at any depth. This static pressure within the oil in the reservoir stratum therefore increases with the thickness of the stratum, the static head developed in a body of saturated oil sand 100 feet thick being ten times that possible in a sand only 10 feet thick. Since pressure within a fluid is exerted equally in all directions, in the lower portions of thick sands considerable lateral pressure will be developed, comparable in magnitude, in some cases, with the pressure exerted by natural gas. In the lower horizons of an oil sand 100 feet thick, for example, a static pressure of about 40 pounds per square inch will be developed; in a 200-foot sand, 80 pounds per square inch. In some of the southern California fields, productive formations as thick as 800 feet have been logged. If these are without impervious partings, so that downward migration of oil throughout the full thickness of the productive zone is possible, pressures as great as 320 pounds per square inch may be developed merely as a result of the action of gravity. Figure 3[1] will serve to demonstrate the variation in rate of flow for different static pressures corresponding to different heads. In any case, gravitational pressure results in variation in produc-

[1] The graphs of Figs. 3, 5, and 6 are from data given in the thesis of R. S. McIntyre, entitled: *A Study of Factors Influencing the Underground Drainage of Oil Sands*, University of California, 1924, conducted under the supervision of the author.

tivity of sands at different depths, more oil entering the well per unit of wall area near the bottom of the productive formation than near the top. How do such conditions influence the vertical and horizontal movements of oil in the reservoir rock in the vicinity of the well? Does oil in motion through sands possess a pressure equivalent to the full superimposed hydrostatic head, or is this pressure partially reduced by inertia and pore resistance? What is the nature of the hydraulic gradient in the sands within the productive formation in the vicinity of a producing well?

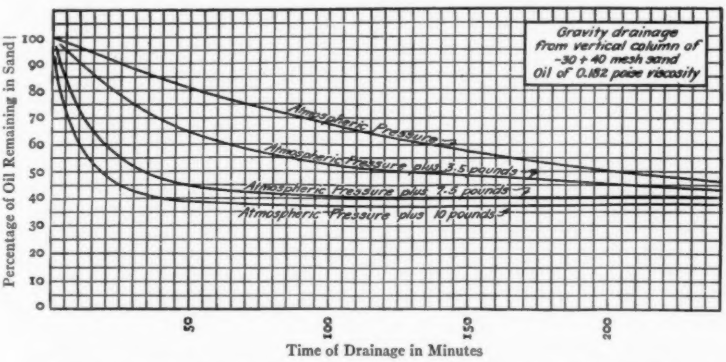

FIG. 3.—Graphs showing results of pressure drainage tests for different static heads (30 to 40 mesh sand, 24.5°B. crude petroleum).

After gas pressure has become exhausted, the oil still remaining in the reservoir rock may continue to flow into the wells as a result of downward concentration of residual oil and the static pressure thus created. Such flow may only be induced, however, by maintaining a fluid level in the well below that in the surrounding sand.[1] This depression of the fluid level within a well will result in gradual depression of the fluid level in the surrounding oil-reservoir rock, the oil surface within the sand assuming a convex-upward surface, the drainage slope gradually flattening and extending farther from the well as drainage proceeds (Fig. 4). The limiting condition for these slopes is a straight line which apparently determines the radius of

[1] L. C. Uren, "The Significance of Fluid Level in Oil Well Pumping," *Transactions, American Institute of Mining and Metallurgical Engineers*, February, 1925.

drainage of the well in so far as gravity is concerned. Considered in terms of three dimensions, this drainage slope virtually forms an inverted cone with the well as the axis. Certain small-scale tests in a glass-walled box made under the direction of the writer have indicated that these slopes are usually less than 5° even for sands as fine as 60 mesh and for very viscous oils. If the angle for a particular set of conditions were 5°, a well penetrating a body of oil sand 100 feet thick would have an ultimate drainage radius, by gravity alone, of 100 divided by the tangent of 5°, or about 1,150 feet. A sand 25 feet thick, on the other hand, would have a drainage

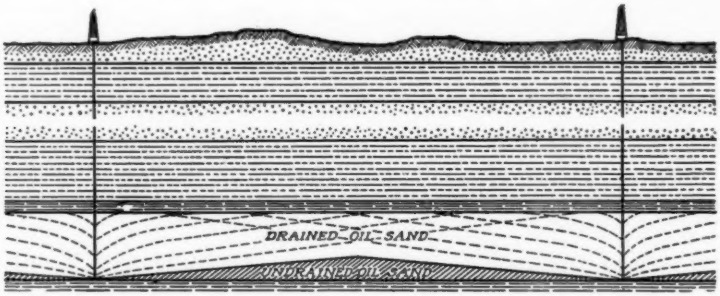

FIG. 4.—Illustrating formation of drainage lines which approach a "critical angle of repose," determining the form and extent of an undrained cone of oil sand between wells.

radius of only 287.5 feet under otherwise similar conditions. When the fluid level in the well is eventually reduced to the bottom of the productive sand, a limiting condition determining the extent of gravity drainage is thus found in what may be termed the "angle of repose" of oil in sand. The slope of this fluid surface and the thickness of the sand will also determine the disposition and extent of a body of undrained oil sand between wells, which will ultimately have an important influence on the problem of well-spacing. With higher oil prices, the oil contained in these undrained areas between present producing wells will in many cases justify the drilling of additional wells intermediate between the old locations.

Realization of these effects of gravity drainage suggests several uncertain factors, which must be investigated before the influence

of gravitational force on the well-spacing problem can be fully evaluated. What is the angle of repose of oil in sand, and how does it vary with the viscosity of the oil and the texture of the sand? What is the form of this equilibrium oil surface: Is it truly conical or is it convex upward or concave upward? To what extent does the fluid level maintained in the well determine the form of this surface before equilibrium is reached?

The effect of edgewater pressure.—The anticlinal theory of oil accumulation requires that everywhere about the edges of an oil deposit the oil-reservoir stratum must be saturated with water. The field evidence shows this to be almost universally true, the edgewater being in most cases under pressure so that it tends to flow up the dip of the structure and replace the oil as it is withdrawn. This edgewater pressure may conceivably exert a considerable influence in forcing oil from the reservoir rock into wells, and hence may influence the economic radius of drainage and economic spacing of wells. In the Bradford field of Pennsylvania, advantage has been taken of the buoyant effect of water in flooding certain portions of the field and forcing the oil into nearby wells from which production has been secured long after normal flow of oil due to gas and gravity pressure had ceased. In certain fields such as the Coalinga field of California, the rate at which the edgewater lines are encroaching toward the heart of the field has been carefully measured. Movement of these edgewater lines is apparently slow. At Coalinga, it has apparently averaged only about 150 feet per year; in the fine-grained sands at Bradford, only 35 feet per year; and experience at Bradford has also shown that when the water wave has proceeded about 600 feet from the center of pressure, all further migration apparently ceases.

It is evident that these edgewater lines are very slow in their readjustments. On the other hand, it must be true that wells in the heart of a field remote from the edgewater lines are able to extract a considerable portion of the oil within their radius of influence, in a few months' time. It would appear, therefore, generally speaking, that wells extract most of their oil before edgewater pressure becomes operative, and that we might dismiss the edgewater influence as a force of almost negligible importance in so far as normal individual well drainage is concerned. While edgewater pressure is

recognized in its broader aspects as a factor of great economic importance—one which in its aggregate effect will eventually be responsible for the recovery of much oil that would otherwise be left in the sands—and while wells near the edgewater lines profit somewhat by the concentrating effect of water pressure upon the oil, it is regarded as too slow in its action to influence production of wells over an entire field to an important degree. At any rate, it is difficult to conceive how wells in the heart of an oil field, surrounded by a screen of other productive wells, will be appreciably influenced by edgewater pressure.

This reasoning suggests several questions worthy of critical investigation: Over what distances may edgewater pressure be effective in sands of different grain size and porosity? For varying degrees of sand texture and pressure, how rapidly may water encroach upon an oil-wet sand? What effect will dip of structure and irregularities in extent of development have in influencing this edgewater pressure?

While the edgewater pressure may be regarded as of minor importance in oil drainage, it must be admitted that the menace of water incursion in oil-producing properties located near the edge of a field will often have an important bearing upon the development program and the spacing of wells. Wells near the edgewater lines should be less closely spaced since they will in all probability be short lived, due to the necessity for early abandonment on account of water incursion.

Having now discussed the natural forces responsible for *expulsion* of the oil from the reservoir rock, let us next turn to the natural forces opposing movement of oil from the sands.

Influence of porosity and texture of the reservoir rock.—The movement of fluids through granular rocks is influenced to an important degree by the size of the openings through which the oil must flow. The quantity of oil that may be stored in a reservoir rock depends directly upon the porosity. These variables are fundamental in any scientific study of well-spacing.

Melcher[1] has contributed valuable data on the porosity of oil

[1] A. F. Melcher, "Determination of Pore Space of Oil and Gas Sands," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 65, pp. 469–97.

and gas sands from which it appears that the space available for oil storage in commercial-oil sands ranges between 4 and 37 per cent of the gross rock volume, apparently averaging about 25 per cent. King[1] has made extensive studies of the lithologic character of sands, of the rate of flow of water through sands, and of the pore resistance offered by varying sizes of sand for different rates of flow. Slichter[2] has developed mathematical formulas by means of which it is theoretically possible to compute the rate of flow of a fluid through sand of a given grain size and porosity. Much of King's and Slichter's data, though concerned primarily with water drainage, bear directly upon the oil-drainage problem. Further experimental work must be done, however, to develop the necessary constants and exponents for use in Slichter's formulas, and to adapt them to the unique conditions attending oil and gas drainage.

The following questions indicate to some extent our present uncertainty regarding the practical influence of the sand factors on the problem of well-spacing: What amount of resistance is offered by sands of different grain size and porosity to the flow of oils of varying viscosity? How does this resistance vary with change in the rate of flow? What effect will converging flow toward a well outlet have in altering the resistance offered by the sand at different distances from the walls of the well? Does flow due to expansion from within, caused by the influence of dissolved and occluded natural gas, vary materially from the normal hydrostatic flow conditions studied by King and Slichter?

The grain size also influences, to an important degree, the amount of oil retained by the sand as a result of capillarity and adhesion. Capillarity is effective only in openings of certain size. The effect of grain size on percentage of oil retained is illustrated in Figure 5. Apparently sands finer than 30 mesh may retain important amounts of oil by capillary action, after all normal drainage due to gas pressure and gravity has ceased.

The mineral grains composing a sand present an enormous surface to the oil, so that considerable quantities of oil are retained by

[1] F. H. King, "Principles and Conditions of the Movements of Ground Water," *U. S. Geol. Survey, Ann. Rept.*, 1897–98, Part 2.

[2] C. S. Slichter, "Theoretical Investigation of the Motion of Ground Waters," *Nineteenth Ann. Rept., U. S. Geol. Survey*, 1897–98, Part 2.

adhesion. Oil has the property of wetting rock surfaces, and the film of adhering oil left on the surfaces of the sand grains represents an appreciable and inevitable loss. Computations based upon the assumption that the sand grains are perfect spheres indicate that for 10- to 20-mesh sand, about 836 square feet of rock surface is in contact with the oil for each cubic foot of oil sand. The areal surface increases as the size of grain decreases, 50- to 60-mesh sand presenting a surface of more than 3,700 square feet per cubic foot of sand. The viscosity of the oil determines the thickness of the oil film left on the sand. If this film is only 0.0002 inch thick, as much as 16

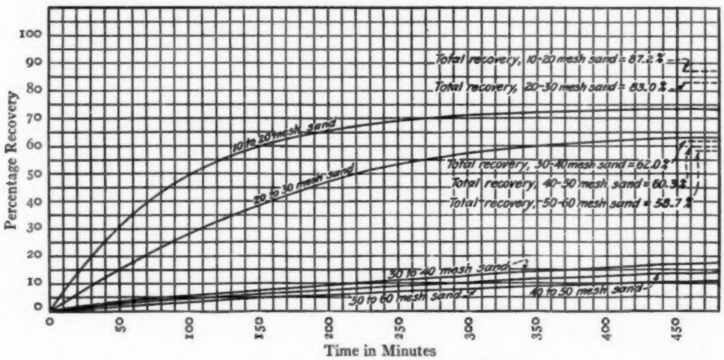

FIG. 5.—Graphs showing influence of size of sand grains on retention of oil, using 19°B. California residuum fuel oil.

per cent of the oil necessary to saturate the voids will be retained in forming the adhering film on 50- to 60-mesh sand. These films are impossible to remove by any known method short of actually mining the sands, disintegrating them, and subjecting them to the action of solvents or distilling temperatures. The percentage of oil retained by capillarity and adhesion probably marks the lower limit of possible recovery by drainage into wells.

While Washburne, McCoy, and others have made important contributions to our knowledge of capillarity and its influence on oil accumulation, there is still opportunity for a great deal of experimental work in determining just how important a rôle capillarity plays in oil drainage. To what extent do different crude petroleums

vary in surface tension? In what sizes of openings is capillary force effective in the case of viscous oils? Is it a force which under all conditions opposes oil drainage, or may it sometimes assist in the accumulation of oil in partially drained sands? How rapid is capillary movement of oil in sands and over what distance may its influence be exerted? May water-wet sands exert capillary influence on oils, and to what extent may oil in oil-wet sands be displaced by water under the influence of capillary force? Again, in the case of adhesion: To what extent does the thickness of the adhesive oil film vary with differences in the viscosity of the oil and with differences in the character of the mineral-grain surfaces? What proportions of the original oil content will be retained by adhesion for sands of different grain size? The greater the percentage of oil retained by capillarity and adhesion, the lower will be the percentage recovery possible—a factor of considerable importance in determining the economic spacing of wells.

Influence of oil viscosity.—The influence of oil viscosity upon the resistance to movement offered by the sand pores and upon the thickness of the adhering films has already been mentioned. Oils of low viscosity are able to move much more freely through a granular rock than are the more viscous oils, and hence the character of the oil influences to some extent the distance apart at which wells may be profitably spaced. Variation in rate of movement of oils of different viscosity is illustrated in Figure 6. In this connection it should be pointed out that ground temperatures have an important bearing upon oil viscosity. A remarkable decrease in viscosity will often be produced by 50° or 100° increase in Fahrenheit temperature. It is well known that at the depths from which many oil wells produce today, ground temperatures are materially higher than they are near the surface, and due account must be taken of the effect of this elevated temperature in any study of oil viscosity. Recent publications of the United States Bureau of Mines have given us a great number of viscosity determinations of crudes from the various United States fields, but information on prevailing ground temperatures in the productive horizons of our oil fields is notably lacking.

The influence of the diameter of the well.—The rate of production and ultimate production of a well will increase as its diameter is

increased. More than half of the energy necessary to force oil from the perimeter of the drainage radius of a well is consumed in moving the oil through the last 10 feet in the immediate vicinity of the well. This is due to the greater speed with which the oil must move as the flow cross-section decreases. At the walls of a 6-inch well, for example, the oil is flowing through the sands forty times as fast as it is at a distance of 10 feet from the axis of the well. The writer has proposed a method of forming a cavity about the well within the oil sand to take advantage of this increased production resulting from increased wall area, and has shown that if such a cavity 20

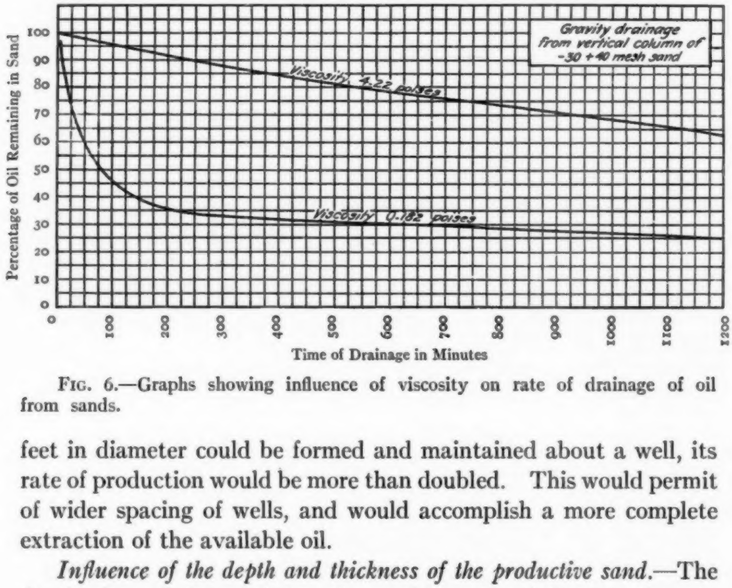

FIG. 6.—Graphs showing influence of viscosity on rate of drainage of oil from sands.

feet in diameter could be formed and maintained about a well, its rate of production would be more than doubled. This would permit of wider spacing of wells, and would accomplish a more complete extraction of the available oil.

Influence of the depth and thickness of the productive sand.—The depth of an oil deposit below the earth's surface influences the economic spacing in two ways: Depth adds directly to the drilling and operating costs, an influence which in most cases is partially offset by the greater oil pressures characterizing the deeper deposits. Greater pressures would normally indicate more complete recovery

[1] L. C. Uren, "Increasing the Production of Petroleum by Increasing the Diameter of Wells," *Trans., Amer. Inst. Min. Met. Eng., Paper No. 1364-G,* September, 1924.

of the available oil, but this advantage is more than counteracted by the rapid increase in the cost of development and operation with increased depth; hence deeper production in nearly every case will prescribe wider spacing of wells.

The thickness of the reservoir rock determines, along with its porosity, the space available for oil storage, and has therefore a direct bearing upon the selection of a proper interval between wells. As the thickness of the oil sand increases, so will the ultimate production per acre increase, and the greater this latter factor, the greater will be the number of wells that a given acreage will support.

A mathematical formula for computing the production of a well.—Careful study of the factors thus far discussed indicates the existence of a definite relationship between them, and suggests the possibility of developing a formula embodying the several physical variables, which would enable us to predict the production of a well under any given conditions. This has been attempted by Slichter, D'Arcy, Hazen, and others who have offered various formulas for use in computing the flow of water through the sands. The formulas deduced by Slichter[1] would appear to apply equally well in the computation of oil flow, since they contain a variable representing the viscosity factor. Following is one of the formulas developed by Slichter for computing the flow of oil through tubes filled with sand:

$$Q=\frac{0.2012\,pd^2s}{uLK}, \tag{1}$$

in which Q is the quantity of fluid flowing in cubic feet per minute; p is the pressure drop, expressed in feet of water; s is the area of cross-section of the tube in square feet; d is the "effective diameter" of the sand grains, measured in millimeters; u is the absolute viscosity of the fluid in poises; L is the length of the drainage channel in feet; and K is a constant depending upon the porosity of the sand. It appears from Slichter's results that the constant K in equation (1) varies markedly with the size of the sand grains. Adopting a new symbol o to represent the percentage porosity, K will vary as some function of o; that is, $K=Co^x$. From the data of Table III of

[1] C. S. Slichter, "Theoretical Investigation of the Motion of Ground Waters," *Nineteenth Ann. Rept., U. S. Geol. Survey*, 1897–98, Part 2.

Slichter's "Field Measurements of the Rate of Movement of Underground Waters,"[1] it is possible to develop an exponent for *o*, which enables us to re-write the foregoing equation as

$$Q = \frac{Cpd^2 s o^{3.3}}{uL}, \qquad (2)$$

in which *C* is a constant.

If we now assume *L* to be the radius of drainage of a well, *R* the radius of the well, and *T* the thickness of the oil sand from which it produces—all expressed in feet—we may integrate equation (2) to find an expression representing the pressure loss suffered by oil in flowing into a well from the surrounding drainage area. The result will be an equation of the following form:

$$p = C \log_{10} \frac{L}{R} \frac{QU}{td^2 o^{3.3}}, \qquad (3)$$

C being a constant differing from that in equation (2).

Most geologists would be unwilling to admit that the physical factors involved in oil drainage are sufficiently uniform and measurable to be placed on a mathematical basis. It must be admitted that while continuous sand strata of uniform texture and considerable thickness are occasionally found, the productive sands are more frequently a part of a productive "zone" in which relatively thin oil-saturated sands are interstratified with thin and more or less impervious layers of shale. The sand strata, furthermore, are not always continuous over great distances, but are frequently lenticular, or they show a tendency to "pinch out" or merge into layers of less porous materials.

Many authorities picture the drainage of oil from the sand as occurring along irregular, dendritic lines or channels determined by the position of the coarser sands which offer the least resistance to flow. Movement of the oil, it is claimed, will be largely influenced by crevices marking the position of bedding-planes and other structural irregularities. The writer prefers to regard drainage as occurring through sheet openings of considerable width rather than through narrow channels.

[1] *U. S. Geol. Survey Water Supply Paper 67.*

Such conditions as have been described above make the analysis of the oil-drainage problem exceedingly complex, and to practical-minded investigators, often seem to exclude consideration of theoretical deductions of the sort forming the main theme of this paper. While such conditions are known to influence the drainage of oil to an important degree, it may be argued in favor of the academic concept of a perfectly uniform, continuous sand reservoir that such an ideal represents the condition under which the maximum beneficial effect of the expulsive forces would be secured. Admittedly, lack of continuity and variation in texture of the sands would influence this ideal result, but as a measure of the maximum drainage effect possible under a given set of conditions, a study of the results obtained under the ideal condition is surely worth while.

Whether or not we are willing to agree that the variables involved in oil drainage may properly be reduced to formula, careful study of such a formula as formula (3) above discloses certain relationships that are not so readily deduced by other means. It is made apparent, for example, that the area drained by a well is not constant, but varies with the pressure existing within or behind the oil, and with the rate of flow of the oil. Other factors remaining constant, the radius of the drainage area will decrease rapidly as the pressure declines. It seems that a well should attain its maximum radius of drainage soon after completion, but thereafter it suffers a gradual decline in its radius of influence; hence a suitable interval between wells today will be too great a year or so hence when pressures have declined to lower levels. The computations should be based upon the estimated average pressure during the productive life of the field.

Before such formulas as those presented can be applied in a practical way, additional data will be necessary. What is a suitable value for the constant C in equation (3)? How is the formula influenced by depression of the fluid surface in the productive sand in the vicinity of the well? The formula is deduced from considerations pertaining to an oil-saturated sand. To what extent may it apply in a partially exhausted sand? How is the formula modified by well interference, when, for example, one well is drilled within the radius of drainage of another?

The influence of geologic structure.—While the effect of geologic

structure has not been given consideration in the development of the foregoing formulas, its influence must be taken into account in the final analysis. Wells may be more widely spaced in the direction of the dip than in the direction of strike if the force of gravity has any significance. On the other hand, steeply inclined structures dictate a closer spacing because of the greater volume of reservoir rock per acre. Local irregularities in structure creating especially favorable conditions for oil accumulation will suggest a closer spacing. The presence of two or more productive sands or zones superimposed one over another will present conditions requiring a decision between the two alternatives of drilling a separate series of wells to produce from each sand, or of producing from one sand at a time and progressively deepening the wells as the upper sands become exhausted. It is seldom that wells may produce from more than one zone at a time, due to differences in pressure in the different zones, or to the presence of intermediate water sands. The static head developed within the well by oil from the upper of two zones would in most cases be sufficient to prevent any flow into the well from the lower zone.

The factors thus far discussed are all physical variables which determine the quantity of oil that we may secure under a given spacing and arrangement of wells. If we were fully informed on the quantitative effect of each of the several factors, and their influence one on another, we should be able to predict the amount of oil that a given property would produce for different assumed intervals between wells; and further, we should be able to determine the amount of oil likely to be produced during each year of the productive life of the property. With such data before us, however, the problem of well-spacing is only half solved, for we must still give consideration to the economic factors involved.

ECONOMIC FACTORS

The value of an oil property is limited by the discounted or present-day value of future profits derived from the sale of its product. Profit is the difference between income from the sale of product and cost of production. Income is determined by multiplying the volume of production by the selling price per unit of volume. The cost of production is made up of several elements, including the

cost of acreage, the cost of development, the cost of plant and physical equipment, and the cost of operation. All of these are important factors in determining the economic spacing of wells. The oil recovery obtained from the property will also be dependent upon certain other economic factors, such as the efficiency of operating the wells and the competitive conditions attending development and production.

The interest-earning capacity of money influences the spacing of wells in two ways: (1) it operates to reduce the apparent value of future income in the computation of present-day values, and (2) is a measure of what the investor considers a fair return in the way of profit on his capital investment. Money invested in the oil-producing industry should command a somewhat higher rate of interest than is appropriate for the ordinary manufacturing enterprise, because of the greater element of risk involved. Oil-producing properties are wasting assets which must return their capital cost before any profit can be said to result. Each oil-company dividend is a return of both principal and interest.

At interest rates of 10 or 12 per cent—rates considered appropriate for partially or even fully developed oil properties—the present value of future expected profits diminishes rapidly. A dollar due five years hence, discounted at 10 per cent, is worth only 62.1 cents; if it is to be received ten years hence, it is worth only 38.6 cents; and if discounted over a twenty-year period, its present value is only 14.9 cents. Because of the loss occasioned by delay in realization on the value of the oil in the ground, every effort must be made to produce and market the maximum quantity of oil in the shortest possible time. This cost element, which we may call the "interest cost of deferred production," therefore favors closer spacing of wells; but, after a certain point, it is offset by the increased interest charges on the capital investment involved in drilling and equipping the greater number of wells, and by their increased operating cost. There must be a certain economic number of wells for any given rate of production for which the algebraic sum of the different cost elements will be a minimum.

The cost of production.—In addition to the operating charges, the cost of production properly includes depreciation charges, represent-

ing the cost of physical plant, and depletion charges designed to redeem the cost of the land and its development. If wells are deep, drilling costs and operating costs will be higher than in shallow territory. The cost of physical plant on an oil lease increases with the number of wells. Higher oil-production costs, irrespective of the cause, favor wider spacing of wells, that is, in deep territory where production costs are relatively high, wells must be spaced at greater distances apart than in the case of shallow wells, other factors remaining constant. If sufficient comparative cost data are at hand, it should be possible to estimate closely the unit cost of production for any assumed conditions and for any number of wells.

Influence of the selling price of oil.—The future revenue of an oil property must depend largely upon the selling price which the product will command at the time it is sold. This, of course, cannot be precisely foretold or even approximated on any scientific basis, but may be estimated from a study of the trend of past and present markets and from a consideration of the probable demand for petroleum and petroleum products and of the probable extent of competition with substitute commodities. The price of petroleum is fundamentally concerned with the available supply. A study of oil reserves, both above and below ground, of the trend of production in the producing areas—that is, whether it is increasing or decreasing—and of the probability of new discoveries or of extensions of old fields, will lead one to some conclusion concerning the available supply for the future. Price is measured by the algebraic sum of the supply and demand factors. If supply is increasing in a greater ratio than demand, prices will be depressed; and if the price is to increase, it must be the result of either increase in demand relative to supply, or decrease in supply relative to demand. These are self-evident economic truths that form the basis of future price estimates.

Most present-day valuations of oil properties are based upon the assumption that future oil prices will be at a somewhat higher level than has prevailed in recent years. A study of the available underground reserves and the rapidly expanding markets for petroleum products leads inevitably to this conclusion. Waning production coupled with increased demand should increase petroleum prices progressively until limited by competition with substitute products.

Obviously, no method of estimation can enable one to predict minor crests and troughs in the future price curve, or temporary depressions or inflations in market conditions, but a close study of the economic factors involved will enable him to predict the general price trend.

Increase in oil values will justify closer spacing of wells. If oil were worth five dollars per barrel, it would be profitable to drill and operate wells for a much smaller daily production than would be possible for dollar oil. This prescribes a higher percentage of extraction and closer spacing of wells when oil increases in price. A proper interval between wells today may be far too great ten years hence, and we may then find it profitable to drill intermediate wells between the old locations for small productions obtained by gravity flow from sands not completely drained by the earlier wells.

The influence of competitive conditions.—Where land is held in small tracts by separate interests, the obligation to offset a neighbor's boundary wells may determine a program of development and an interval between wells detrimental to the interests of either or both parties. The evils of town-lot drilling have been demonstrated in several fields. Aside from the detrimental influence of close spacing of wells along boundaries in the case of small tracts, it will often happen that the location of these boundary wells will in a large measure prescribe the location and number of interior wells. If we had more definite knowledge of the factors governing well-spacing, we might hope to secure more universal observance among operators of a definite program of development involving the maintenance of a proper interval between wells by common agreement.

Influence of efficiency in production.—A producer who operates his wells in such a way as to secure more rapid recovery and a greater percentage of extraction of the available oil than his neighbors can afford to space his wells farther apart. Maintenance of proper fluid levels in pumping wells,[1] maintenance of pumping equipment at maximum efficiency, freedom from sand and water incursion, and freedom from interruptions in operation will have a decisive effect upon the ultimate recovery of the oil. The use of vacuum, air pressure, or water pressure as aids in securing a more complete recovery

[1] See footnote 1, p. 199.

will also justify wider spacing of wells, as will prevention of the waste of natural gas by maintenance of moderate back pressures.[1]

Production records as a basis for determining well-spacing.—It is quite possible to demonstrate well interference and to approximate the distance apart at which wells must be spaced to avoid mutual interference, by a careful study of individual well-production records. Studies of the production graphs of offset wells spaced at varying distances apart will perhaps disclose the spacing which will be productive of the maximum *amount* of oil; but this is not necessarily the *economic* interval between wells which will result in maximum *profit*. The production of a well is, in itself, a measure of the composite effect of the different variables aiding and opposing movement of the oil from the sand; but without knowledge of the quantitative effect of each individual variable, we would be unable to apply the records of one field or locality in determining the proper spacing in another area under slightly different conditions. If production records are to be the basis for determination of the proper interval between wells, it is obvious that we must wait for several years after the field is first developed before we can measure the results of the early development. We should be able to prescribe the proper spacing of wells during the early years of development before the results of the early wells can be made available. Postmortems on what should have been the spacing in a particular field are interesting, but of little practical value.

CONCLUSIONS

The conclusions reached in the foregoing discussion are summarized in Table I, which indicates the qualitative effect of each of the several variables on the spacing of wells. To determine the composite effect of all of these variables in a particular field or under a given set of conditions is a difficult task; and yet it can be accomplished if we have sufficient data on the quantitative effect of each variable. The necessary information can only be secured by an organized program of research and field study. Some of the factors can best be determined by laboratory experimentation in which the several variables can be kept under close control and the results of

[1] See footnote 1, p. 197.

variation in individual factors definitely measured. Other factors require an extensive study of costs and statistical records. Some must be approached from the field-production records.

Universities and research institutions will be able to assist in certain phases of this work. The problem is one that can well be worked out by the technical staffs of any of our larger oil companies with their great resources, excellent research facilities, and ready

TABLE I

QUALITATIVE EFFECT OF VARIOUS ECONOMIC AND PHYSICAL FACTORS ON THE SPACING OF WELLS

Increase In	Spacing of Wells
Gas pressure	Increased
Gravity pressure	Increased
Edgewater pressure	Increased
Porosity of reservoir rock	Decreased
Grain size of sand	Increased
Oil viscosity	Decreased
Diameter of wells	Increased
Depth of productive sand	*
Thickness of productive sand	Decreased
Dip of structure	*
Number of productive sands or zones	Decreased
Discount or interest rate on deferred production	Decreased
Interest on capital investment	Increased
Cost of development	Increased
Cost of operation	Increased
Selling price of oil	Decreased
Size of property	Increased
Efficiency of production	Increased

* Items marked with an asterisk may prescribe either decreased or increased spacing, depending upon which of two considerations related to the variable named is regarded as most important.

access to field records; but if prosecuted in this way the results are not made public, and there must be great duplication of effort by many different companies if our oil fields, considered as a whole, are to be intelligently developed. It would seem to be a problem of the type that could best be studied by some public or semipublic institution such as the United States Bureau of Mines, or by some research institution adequately financed, say, by the American Petroleum Institute.

The work might be financed in part by our state governments. In California, for example, the state receives, as its share of bonuses and royalties paid to the national government under the operation of the Mineral Land Leasing Law, an annual sum which at present ranges between $200,000 and $300,000. The reinvestment by the state of a small part of this sum in research in the industry responsible for its production would be a thoroughly justifiable proposition, particularly since the investment would in all probability result in higher ultimate returns in royalty payments.

As an outcome of such a study, we might hope to have made available to the industry as a whole a simple and direct means of determining the economic interval between wells for any prescribed conditions; or, perhaps, definite recommendations for the spacing of wells in each of the different fields of the United States. The immediate result of such an investigation would be a substantial increase in profits on oil production and a more efficient recovery of our remaining petroleum reserves. It is a problem worthy of the serious attention of the entire oil-producing industry and of the best efforts of every individual sincerely interested in its welfare.

THE RELATION BETWEEN THE OPEN-FLOW GAUGE AND THE WORKING CAPACITY OF GAS WELLS[1]

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ABSTRACT

Various difficulties have made very unreliable the conclusions drawn from open-flow gauge readings on gas wells. Studies to determine the relation of the open-flow gauge to actual working capacity were undertaken on a group of sixty-seven wells for which data covering a period of six years were available. It appears that the open-flow gauge has very doubtful value for any individual well and it disregards conditions under which the well must operate. Over a long period of time and using many wells the ratio of open-flow gauge to line delivery averages close to 33 per cent, this figure being usable as a factor in estimating delivery.

For many years the open-flow gauge has been the prevailing method of estimating the daily potential production of gas wells. The measurement is taken with a Pitot tube[2] by placing an extension of one arm of the U within the opening from which the gas issues, at one-quarter to one-third of the diameter from the edge, and observing the difference in level between the fluid in each arm, using either water or mercury as the liquid, depending upon the size of the well. The difference in level, expressed in tenths of inches, is converted into cubic feet of gas deliverable per day by means of well-known tables which have been computed from the pressure, density of the gas, and the size of the opening.

With the Pitot tube at least five definite steps are required in taking the gauge, two of which require the judgment of the operator, and three of which are subject to possible error. It is first customary to blow the well down to low pressure before taking the

[1] Presented at the meeting of the American Association of Petroleum Geologists, March 27–29, 1924.

[2] Measurements with the Spring gauge are not within the scope of this paper.

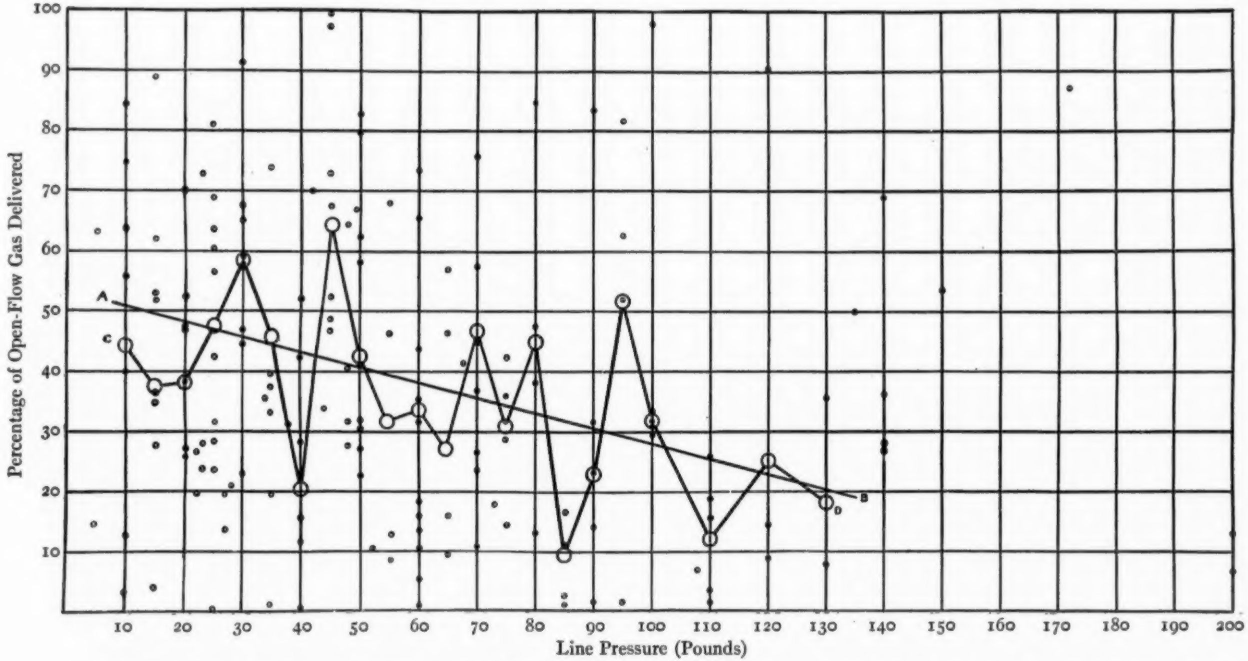

FIG. 1.—Chart showing graphically the relation between the line pressure and the percentage of open-flow gas actually delivered. Each point on the chart represents the percentage of open-flow gas delivered by some particular well on a certain date against the indicated line pressure. Line *C–D* joins the points which represent the average percentage of gas delivered against the various line pressures. Line *A–B* is drawn to eliminate some of the irregularities in line *C–D*, and to show the approximate relation between the open-flow gas and the actual delivery at various line pressures.

gauge, even though very few wells require the same length of time for the pressure to be blown off, and the term "blown off" is not so well understood that the method is standardized and not subject to individual opinion. In placing the extended arm of the U-tube within the well opening, the gauger must estimate one-third or one-fourth the diameter of the hole, and in reading the gauge the difference in level between the two sides of the tube must be observed.

TABLE I

Comparison of Open-Flow and Actual Gas Deliveries

Well No.	Gauge	Open-Flow Volume Feet per Day	Metered Gas Feet per Day	Percentage Delivered	Line Pressure in Pounds
	July, 1918				
1..........	50/10 W 2"	330,720	168,870	51.06	....
2..........	60/10 M 2	1,360,800	3,710	0.27	....
3..........	4/10 M $6\frac{5}{8}$	12,300,000	3,724,600	30.28	....
4..........	14/10 M 3	1,480,000	580,650	39.23	215
5..........	6/10 M 2	431,000	4,290	1.00	85
Total..	....	15,902,520	4,482,120	28.18	150
	September, 1919				
2..........	4/10 W 2"	94,560	900	0.9	60
5..........	4/10 W 2	94,560	3,500	3.70	....
6..........	10/10 M 2	150,792	29,400	19.50	35
7..........	8/10 M 2	3,108,000	375,670	12.09	40
8..........	2/10 W 2	67,392	14,100	20.92	28
9..........	20/10 M 2	786,720	252,000	32,03	220
10..........	16/10 W 2	187,000	59,600	31.87	60
11..........	22/10 W 2	223,120	49,160	22.03	....
Total..	....	4,862,864	895,090	18.41	71.86

The chance of error here is at least twice that which might occur if only one position of the liquid were to be noted. In addition to these the nature of the liquid and the size of the opening must be recorded.

When all of these facts are recognized it becomes extremely doubtful that given ten wells and ten different gaugers, each to test every well, that any safe degree of similarity can be expected, while, on the contrary, many errors and differences in the results are to be anticipated. In looking over a great many gauges covering

a period of about twelve years, many instances were found where a gauge was taken in a small opening and then in a large one at the same well, and in no instance did these readings, when converted into cubic feet per day, agree absolutely, and in many cases they differed by as much as 100 per cent.

TABLE II

COMPARISON OF OPEN-FLOW AND ACTUAL GAS DELIVERIES

Well No.	Gauge	Open-Flow Volume Feet per Day	Metered Gas Feet per Day	Percentage Delivered	Line Pressure in Pounds
	July, 1920				
1	14/10 W 2"	179,000	29,290	16.36	27
2	20/10 W 1	53,280	5,840	10.96	70
4	10/10 M 3	1,247,400	200,000	16.03	210
7	30/10 W 2	260,640	122,600	47.04	20
8	14/10 W 3	410,000	273,840	66.79	49
9	18/10 M 2	734,000	329,870	44.94	225
11	16/10 W 2	187,000	122,800	65.67	60
12	48/10 W 2	328,000	28,000	8.54	55
13	2/10 M 2	248,640	243,870	98.08	100
Total	....	3,647,960	1,356,110	37.17	90.66
	December, 1921				
2	44/10 W 2"	304,320	96,940	31.85	100
4	12/10 M 2	604,000	526,710	87.20	172
9	12/10 M 2	604,000	418,200	69.23	140
11	36/10 W 2	281,568	87,400	31.04	100
13	34/10 M 3	725,280	206,420	28.46	225
14	40/10 W 2	....	....	....	....
Total	....	2,519,168	1,335,670	53.20	147.40

Since the open-flow gauge does not even consider the working conditions or the line pressures against which the well must operate, its value as an indication of the potential daily production of a well is thus seen to be decidedly questionable, and with these facts in mind some studies of the relation of the open-flow gauge to actual metered-gas deliveries have been carried on with 67 wells and some 250 tests, covering a period of six years. At the suggestion of Mr. C. B. Turner, general manager of the South Penn Oil Company, these have been worked up to show the percentage of open-flow

gas which the wells actually delivered. Since metered-gas readings are usually available only on a monthly basis, the monthly values

TABLE III

COMPARISON OF OPEN-FLOW AND ACTUAL GAS DELIVERIES

Well No.	Gauge	Open-Flow Volume Feet per Day	Metered Gas Feet per Day	Percentage Delivered	Line Pressure in Pounds
	June, 1922				
11	8/10 W 2″	134,400	84,300	62.72	95
12	6/10 W 2	115,968	300	60.26	40
14	5/10 W 2	105,792	15,330	14.49	75
16	11/10 W 2	153,720	61,400	39.94	10
17	10/10 W 1	37,680	21,630	57.40	30
18	2/10 W 2	67,392	25,870	38.39	20
19	4/10 W 1	23,640	7,470	31.60	90
20	3/10 M 2	304,320	144,900	47.61	80
22	22/10 W 2	223,120	70,300	31.51	25
Total	....	1,166,432	431,500	36.99	51.67
	September, 1922				
1	4/10 W 2″	94,560	70,730	74.80	10
11	8/10 W 2	134,400	69,730	51.88	95
12	16/10 W 1	47,080	5,000	10.60	35
13	14/10 M 2	650,180	85,500	13.15	200
14	5/10 W 2	105,792	33,500	31.66	75
15	2/10 W 2	67,392	154,100	88.98	15
16	5/10 W 2	105,792			
17	10/10 W 2	150,720	4,930	3.27	10
19	4/10 W 1	23,640	8,000	33.84	44
20	30/10 W 1½	146,610	124,270	84.76	80
22	16/10 W 2	187,320	113,430	60.55	25
24	12/10 M 2	604,400	43,970	7.27	....
25	68/10 W 1	98,280	65,000	12.28	....
26	6/10 M 2	431,040			
27	20/10 W 2	213,120	75,130	6.77	200
28	26/10 M 2	895,840			
29	10/10 W 2	150,720	5,300	3.52	....
30	70/10 W 2 16/10 W 6⅝	399,120 1,958,880	377,200	16.00	....
31	1/10 M 3	396,360	101,830	25.69	20
32	25/10 W 3	535,680	192,230	35.89	25
Total	....	7,694,526	1,529,850	19.88	64.15

have been converted into deliveries per day and compared with the open-flow gauge either at the beginning or at the end of the same month. These relations are shown in the accompanying tables.

For the entire period of six years the percentage of gas delivered ranges from a minimum of about 1 per cent in some wells to a maximum of 98 per cent in others, with the average of various groups

TABLE IV

COMPARISON OF OPEN-FLOW AND ACTUAL GAS DELIVERIES

Well No.	Gauge	Open-Flow Volume Feet per Day	Metered Gas Feet per Day	Percentage Delivered	Line Pressure in Pounds
	December, 1922				
1.........	3/10 W 2"	83,040	52,520	63.25	5
8.........	56/10 M 2	1,314,200	473,290	36.01	75
12.........	8/10 W 1	33,600	19,350	57.59	30
13.........	10/10 M 2	554,400	157,870	28.48	280
14.........	4/10 W 2	94,560	28,000	29.61	100
15.........	4/10 W 2	94,560	122,810	51.69	15
16.........	9/10 W 2	143,040			18
17.........	3/10 W 2	83,040	11,810	14.22	5
19.........	3/10 W 1	20,760	13,390	64.50	48
20.........	26/10 W 2	243,640	149,260	61.26	68
21.........	12/10 W 2	165,960	165,230	99.56	45
22.........	13/10 W 2	176,160	111,390	68.91	25
23.........	32/10 W 1	63,160	39,160	62.00	15
24.........	8/10 M 2	497,280	67,160	13.51	60
25.........	3-9/10 W 1	75,080	91,580	43.72	60
26.........	8/10 W 2	134,400			
27.........	20/10 M 1	196,680	213,190	22.89	60
28.........	18/10 M 2	734,720			380
					380
29.........	8/10 W 2	134,400	17,350	12.91	55
31.........	2/10 W 3	151,632	106,550	70.27	20
32.........	23/10 W 3	513,000	92,770	18.08	73
33.........	8/10 W 2	134,400			55
34.........	6/10 W 2	115,968	170,290	68.02	55
35-36......	43/10 W 2	312,720	157,030	50.21	50
37.........	90/10 W 2	452,160	377,290	83.44	50
38.........	6/10 W 2	115,968	45,420	39.17	35
39.........	8/10 W 2	134,400			
40.........	7/10 W 2	126,240	162,480	44.34	....
41.........	5/10 W 2	105,792			
Total..	....	7,004,960	2,855,190	40.76	79.31

of wells showing a minimum of 18 per cent and a maximum of 53 per cent. The average of all the wells for the entire period is 32.4 per cent. Probably some of the extreme high and low values are the result of errors in observation, though they all tend to show that the open-flow gauge as applied to any individual well is an unsatisfactory

measure of its value, though for a large group of wells a delivery of somewhere near $33\frac{1}{3}$ per cent may safely be expected.

In order to show the relation between actual line delivery and

TABLE V

Comparison of Open-Flow and Actual Gas Deliveries

Well No.	Gauge	Open-Flow Volume Feet per Day	Metered Gas Feet per Day	Percentage Delivered	Line Pressure in Pounds
	February, 1923				
1	2/10 W 2″	67,392	37,640	55.85	10
9	18/10 M 1	185,800	169,680	91.32	30
11	13/10 W 2	176,000	47,040	26.73	70
13	8/10 M 2	497.280	192,500	38.71	230
14	5/10 W 2	105,792	24,540	23.20	90
15	6/10 W 2	115,968	158,860	63.45	10
16	8/10 W 2	134,400			15
17	16/10 W 1	47,080	13,320	28.29	25
19	3/10 W 1	20,760	1,440	6.94	108
20	8/10 W 2	134,400	109,710	81.63	95
22	24/10 W 2	233,080	63,140	27.09	20
23	3/10 W 2	83,040	28,860	34.75	15
24	8/10 M 2	497,280	69,960	14.07	90
25	8/10 M 2	497,280	104,890	11.30	85
26	6/10 M 2	431,040			85
27	10/10 M 1	138,600	205,540	25.90	110
28	14/10 M 2	655,000			110
29	28/10 W 2	252,640	3,110	1.23	90
31	14/10 W 2	179,160	84,500	47.16	20
32	5/10 M 2	393,120	78,470	19.96	22
33	6/10 W 2	115,968	183,790	62.27	50
34	14/10 W 2	179,160			90
35	8/10 W 2	134,400	130,860	48.68	45
36	8/10 W 2	134,400			45
37	38/10 W 2	284,000	95,890	33.76	100
38	10/10 M $6\frac{5}{8}$	5,856,850	1,691,000	28.87	....
39	10/10 W 2	150,720			
40	7/10 W 2	126,240	169,790	44.36	....
41	5/10 W 2	105,792			
42	20/10 W 2	213,120	48,640	22.82	50
44	16/10 W $3\frac{1}{2}$	571,200	120,070	21.02	0
46	39/10 W $2\frac{1}{2}$	468,000	354,180	44.25	....
47	20/10 W $2\frac{1}{2}$	332,467			
48	6/10 W 2	115,968	54,390	46.90	30
49	8/10 W 3	302,400	140,000	46.30	65
50	42/10 M 2	1,136,800	734,400	64.60	....
51	27/10 W 2	248,640	168,500	67.77	30
52	7/10 W 2	126,240	30,000	23.76	....
66	15/10 W 1	46,080	21,140	45.88	....
Total	....	15,493,557	5,335,850	34.44	63.28

open-flow gauge in terms of the line pressures the data in the accompanying tables have been plotted graphically, each point on the chart representing the percentage of gas delivered by a particular well at

TABLE VI

COMPARISON OF OPEN-FLOW AND ACTUAL GAS DELIVERIES

Well No.	Gauge	Open-Flow Volume Feet per Day	Metered Gas Feet per Day	Percentage Delivered	Line Pressure in Pounds
	April, 1923				
1..........	2/10 W 2"	67,392	42,600	63.21	10
2..........	40/10 W 1	76,000	68,930	90.70	120
8..........	8/10 W 3	302,400	219,530	72.60	23
9..........	10/10 M 1	554,400	151,800	27.38	50
11..........	15/10 W 2	184,320	49,300	26.75	140
12..........	6/10 W 1	28,992	18,400	63.47	25
14..........	4/10 W 2	94,560	26,370	27.89	140
15..........	2/10 W 2	67,392	145,900	84.25	10
16..........	5/10 W 2	105,792			15
17..........	22/10 W 1	55,280	12,830	23.21	40
18..........	10/10 W 1	37,680	34,500	91.56	....
19..........	2/10 W ½	4,214	1,600	37.97	....
20..........	12/10 W 2	165,960	138,700	83.57	90
21..........	16/10 W 2	187,320	149,800	79.97	50
22..........	30/10 W 2	260,640	136,470	52.36	20
23..........	50/10 W 1	82,680	30,300	36.65	15
24..........	6/10 M 2	431,040	14,800	3.43	110
25..........	4/10 M 2	350,880	10,600	1.36	110
26..........	6/10 M 2	431,040			110
29..........	15/10 W 2	184,320	4,600	2.50	85
31..........	1/10 M 2	168,960	59,670	35.32	60
32..........	22/10 W 2	223,120	58,970	26.43	22
33..........	8/10 W 2	134,400	201,230	57.90	50
34..........	20/10 W 2	213,120			
35..........	4/10 W 2	94,560	137,570	72.74	45
36..........	4/10 W 2	94,560			45
39..........	9/10 W 2	143,040	180,700	46.91	....
40..........	7/10 W 2	126,240			
41..........	6/10 W 2	115,968			
42..........	8/10 W 2	134,400	55,470	41.27	50
44..........	16/10 W 3½	573,539	75,430	13.15	....
46..........	40/10 W 2½	474,739	351,530	43.55	....
47..........	20/10 W 2½	332,467			
48..........	4/10 W 2	94,560	35,200	37.23	35
51..........	30/10 W 2	260,640	169,330	64.97	30
53..........	56/10 W 2	356,640	33,870	9.50	65
54..........	40/10 W 2	304,320	86,970	28.58	75
55..........	5/10 W 2	105,792	1,370	1.29	95
66..........	13/10 W 1	171,960	16,870	9.81	....
67..........	4/10 M 2	350,880	96,570	27.52	48
68..........	14/10 W 2	179,160	176,000	98.24	....
52..........	7/10 W 2	399,120	51,970	13.02	....
Total..	....	8,724,487	3,045,750	34.91	59.13

some particular date against the indicated line pressure. The values have been averaged by taking the total amount of gas metered at each particular pressure and dividing it by the open-flow gauge. The actual position of the line is somewhat erratic, but its general

TABLE VII

Comparison of Open-Flow and Actual Gas Deliveries

Well No.	Gauge	Open-Flow Volume Feet per Day	Metered Gas Feet per Day	Percentage Delivered	Line Pressure in Pounds
	September, 1923				
1	2/10 W 2″	67,392	49,740	73.81	35
2	42/10 W 2	310,680	48,550	15.63	110
8	20/10 W 2	213,120	149,190	70.00	42
9	6/10 M 2	431,040	135,060	31.33	38
11	18/10 W 2	201,000	47,550	23.66	70
12	6/10 W 1	28,992	100	0.34	25
14	4/10 W 2	94,560	17,840	18.87	110
15	4/10 W 2	94,560	12,100	12.80	10
17	40/10 W 1	78,080	7,840	10.30	52
18	4/10 W 1	23,640	12,550	53.09	....
20	30/10 W 2	260,640	130,480	50.06	135
21	8/10 W 2	134,400	130,450	97.06	45
22	20/10 W 2	213,120	125,680	58.97	30
23	2/10 W 2	67,392	35,580	52.80	15
24	10/10 M 2	465,600	41,030	8.81	....
25	7/10 M 2	465,600	32,650	4.00	15
26	4/10 M 2	350,880			15
31	12/10 W 2	168,000	53,740	31.99	50
32	8/10 W 2	134,400	30,870	22.97	30
34 & 43	14/10 W 2	178,000	141,650	51.97	40
	4/10 W 2	94,560			40
35	6/10 W 2	115,968	199,350	67.55	45
36	14/10 W 2	179,160			45
38	6/10 W 2	115,968	45,970	39.64	35
39	9/10 W 2	143,040	167,740	44.72	70
40	7/10 W 2	126,240			70
41	5/10 W 2	105,792			70
44	17/10 W 3½	583,059	93,580	16.05	65
46	10/10 W 2½	235,123	313,230	57.09	25
47	18/10 W 2½	313,560			25
51	2/10 M 2	248,640	88,740	35.69	34
52	8/10 W 2	134,400	49,550	36.87	70
53	72/10 W 2	401,000	23,320	5.82	....
56 & 60	8/10 M 2	497,280	501,060	5.20	60
	7/10 M 2	465,600			60
57	36/10 W 2	285,000	14,940	5.24	....
58	16/10 W 2	187,000	27,130	14.51	120
59	8/10 W 2	134,400	101,770	75.72	70
66	17/10 W 1	49,000	17,810	36.35	140
19	2/10 W ½	4,212	2,550	60.54	....
Total	....	8,398,098	2,849,390	33.93	54.60

TABLE VIII

Comparison of Open-Flow and Actual Gas Deliveries

Well No.	Gauge	Open-Flow Volume Feet per Day	Metered Gas Feet per Day	Delivered Percentage	Line Pressure in Pounds
	December, 1923				
1	2/10 W 2"	67,392	31,230	46.34	55
8	20/10 W 2	213,120	59,230	27.79	23
9	5/10 M 2	431,040	121,900	28.28	40
11	18/10 W 2	201,000	71,520	35.58	130
14	4/10 M 2	350,880	28,030	7.99	130
17	5/10 W 2	105,792	14,130	13.36	27
18	4/10 W 1	23,640	9,210	38.96	....
20	28/10 W 2	256,640	108,680	42.35	75
21	10/10 W 2	150,720	114,000	75.64	65
22	30/10 W 2	260,640			20
23 & 62	20/10 W 1	53,280	205,300	56.87	10
	16/10 W 1	47,080			20
24	7/10 M 2	465,600	77,480	16.64	85
25	5/10 M 2	393,120	109,060	13.23	80
26	6/10 M 2	431,040			85
29	12/10 W 2	165,960	26,680	16.08	60
31	10/10 W 2	150,720	41,680	27.65	15
32	8/10 W 2	134,400	31,740	23.62	23
					45
34 & 43	16/10 W 2	187,320	147,520	52.33	45
	4/10 W 2	94,560			
35	4/10 W 2	94,560			
36	14/10 W 2	180,320	180,190	42.34	40
37	20/10 W 2	280,512			
38	105/10 W 3	1,087,880	787,190	57.53	70
39	10/10 W 2	150,720			48
40	9/10 W 2	143,040	165,420	40.37	48
41	6/10 W 2	115,968			48
44	15/10 W 3½	564,000	110,480	15.59	40
46	16/10 W 2½	280,950	277,030	42.23	25
47	28/10 W 2½	375,000			25
48	6/10 W 2	115,968	51,730	44.61	30
50	20/10 M 2	786,720	389,940	49.57	....
52	8/10 W 2	134,400	42,770	31.82	48
53	6/10 M 2	431,040	78,480	18.21	60
56	44/10 W 2	316,680			50
60	43/10 W 2	313,680	358,650	30.65	50
61	44/10 W 2	316,680			50
65	22/10 W 2	223,120			50
57	3/10 M 2	304,320	31,740	10.43	60
58	16/10 W 2	187,320	16,520	8.82	120
59	20/10 W 2	213,120	99,650	46.76	45
66	15/10 W 1	46,080	24,770	53.75	150
12	8/10 W 1	98,992	6,810	23.49	25
63	30/10 M 2	962,880	366,940	38.11	80
Total	....	11,837,894	4,185,700	35.36	54.88

trend is fairly uniform, and it is about what would be expected; i.e., the higher the line pressure the smaller the percentage of gas delivered, and the lower the pressure the greater the percentage of delivery. For line pressures less than 60 pounds the deliveries average close to 50 per cent, and for pressures close to or above 100 pounds the deliveries run less than 30 per cent, though less data are available at the higher pressures than are desirable.

The result of the investigation may be briefly summarized as follows: (1) The many sources of inaccuracy possible in taking the

TABLE IX

SUMMARY OF RELATION BETWEEN OPEN-FLOW AND METER DELIVERIES

	Open-Flow Volume Feet per Day	Metered Gas Feet per Day	Percentage Delivered
July, 1918	15,902,520	4,482,120	28
Sept., 1919	4,862,864	895,090	18
July, 1920	3,647,960	1,356,110	37
Dec., 1921	2,519,168	1,340,220	53
June, 1922	1,166,432	431,500	36.9
Sept., 1922	7,694,526	1,529,850	19.8
Dec., 1922	7,004,960	2,855,190	40.7
Feb., 1923	15,493,557	5,535,850	34.4
April, 1923	8,727,487	3,045,750	34.9
Sept., 1923	8,398,098	2,849,390	33.9
Dec., 1923	11,837,894	4,185,700	35.3
Total	87,255,466	28,306,770	....
Average percentage of open-flow gas actually delivered			32.44

open-flow gauge make its value very doubtful for any individual well. (2) The open-flow gauge disregards the conditions under which the well must operate. (3) Over a short period the ratio of open-flow gauge to line delivery may vary from less than 1 per cent to almost 100 per cent. (4) Over a long period of time, using many wells, the ratio of open-flow gauge to line delivery averages close to 33 per cent, so that this figure may be used as a factor in reducing any open-flow gauge to an average estimated delivery. (5) The percentage of delivery declines from about 50 per cent for low line pressure to about 25 per cent for line pressure at or slightly above 100 pounds.

CORRELATION OF ORGANIC SHALES IN THE SOUTHERN END OF THE SAN JOAQUIN VALLEY, CALIFORNIA[1]

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ABSTRACT

Correlation of the organic shales in the southern end of the San Joaquin Valley has much economic importance. Investigation of micro-organisms indicates that the upper 4,000 feet of this shale is equivalent to the shale at Monterey where early Miocene sediments are lacking. Local variations in these deposits make stratigraphic subdivisions of general application very difficult but microscopic fossils appear to afford a basis for recognition of different parts of the shale body.

A large part, if not all, of the oil produced thus far in the southern end of the San Joaquin Valley, California, is supposed to have been derived from a mass of underlying organic shales. This condition, together with their wide extent, causes the correlation of them to be matters of considerable importance and interest. Heretofore the application of stratigraphy alone has resulted in some differences in opinion as to the age of the formation, owing chiefly to some extensive complications in structure and variations in sedimentation. In this study it has been attempted to apply paleontologic data to the problem for the first time, and the results indicate that the geology is much more simple than was at first supposed.

The shales in question outcrop more or less continuously on the western and southern borders of the valley from the northern Kern County line southeast almost to Tecuya Creek. In one place they cover the extreme northeastern corner of San Luis Obispo County. The same formation is also found on the east side of the valley near the Kern River oil field and is extensively exposed at many places in the western slopes of the Coast ranges bordering the Pacific from Point Reyes to Los Angeles. These areas lie outside the one here considered and need mention only incidentally at this time.

[1] Manuscript received by the Editor, February 29, 1924.

Much of historical interest will be omitted here for sake of brevity, but the reader will find the subject reviewed by Pack in a professional paper of the U. S. Geological Survey.[1]

Pack called the formation "Maricopa shale," and referred to a "typical" section in Sunset Valley near Maricopa. This name was first used by English[2] to designate certain strata in Cuyama Valley west of the area under discussion, but he and Pack both believed that the upper part of the shale near Maricopa was younger than any to which he applied the name. We have not visited Cuyama Valley to check this point because, as will appear, it is a matter of relatively little importance.

The type locality is an exposure which lies between the town of Maricopa and the foothills to the west. A part of the section may be seen on the road which extends from Maricopa into Cuyama Valley, but much of it is overlapped by the Etchegoin formation (Pliocene) and alluvium. Bitterwater Creek immediately north of the road has cut through the section and exposed more of it, but even here only the lower part of the entire deposit may be seen; the upper part, consisting of 1,000 feet or more, is completely concealed.

About 1 mile southwest of the town of Taft a small patch of the upper layers is folded upward and the covering has been eroded away so that a fairly good exposure may be seen. From that point northward to the Kern County boundary line the exposures are more or less continuous, depending upon the cutting of streams and overlapping of later sediments. Chico-Martinez Creek cuts entirely across the section and exposes it from top to bottom, the thickness being 8,000 or more feet.[3]

The deposits are characteristically yellow, buff, or white, thinly bedded shales composed in large part of amorphous silica. Some of this appears to have been chemically precipitated, but the greater portion consists of the skeletal remains of microscopical organisms, chiefly unicellular algae belonging to the group of Diatomaceae. For a long time the deposits have been called

[1] R. W. Pack, *U. S. Geol. Surv. Prof. Pap. No. 116* (1920), pp. 21, 27, 28.

[2] W. A. English, *U. S. Geol. Surv. Bull. 621* (1916), pp. 198–99.

[3] English measured the section and found it to consist of 8,400 feet to the top of the first reef (*U. S. Geol. Surv. Bull. 721* [1921], pp. 19–20).

"diatomaceous shales" because of the abundance of frustules of diatoms, but many siliceous tests of Radiolaria and spicules of sponges are also intermixed. In certain horizons are found large numbers of calcareous tests of Foraminifera; sometimes these are beautifully preserved but owing to acidic waters which usually accompany siliceous deposits they are often represented only by molds. On account of the complex character of the constituents of the shale the general term "organic" is more applicable than "diatomaceous." To define more clearly the term "organic," it is here assumed to mean a shale having more than 50 per cent of its constituents by bulk of organic origin.

Deposits of this character are widely distributed in California, and for a long time the principal formation was called "Monterey shale" because of its large exposures near the town of Monterey, California. That deposit was clearly described by Blake in 1855,[1] and the name has since been in more or less current use.

On account of the macroscopic similarity of the shales of the San Joaquin Valley with those exposed at Monterey the latter have been taken as a basis of comparison in this study. In the district covered by this report several sections of the formation have been examined and very extensive collections made through these sections. The faunas and floras have been carefully segregated and mounted in the most approved manner. In short, the organisms from valley sections do not differ in sequence, and this similarity of sequence appears to be much closer in the microscopic organisms in the section at Monterey than would be the case with higher organisms, such as the mollusks, found in localities of similar age and closer together.

The basal layers at Monterey contain a fauna of Foraminifera which is easily recognizable in certain layers of the shale in the valley. Proceeding upward in the sequence of sedimentation the similarity of faunas is equally pronounced until at the top at Monterey there is about 100 feet of light, fluffy material composed very largely of diatom frustules of many species. The same situation exists in the exposures in the valley, and upon direct comparison there is no more difference in the assemblage of species than would

[1] *Proc. Acad. Nat. Sci.* (Phila., 1855), pp. 328–31.

be found in a gathering of diatoms off the California coast today from one taken, say, off the Alaskan coast. Such similarity leads to the inevitable conclusion that the deposits at Monterey and in the southern end of the San Joaquin Valley are contemporaneous.

It should not be assumed that the paleontologic work upon which this conclusion is based is meager or that the study of this formation is the first to be made. The paleontology of the Monterey shale has been the subject of a large number of publications in the past, and its diatoms are very well known. It is an interesting fact that the first fossils described from western North America were diatoms and Foraminifera from a deposit of this material exposed on San Francisco Bay. This was in 1853. A list compiled in 1893 gives 232 species of diatoms from the formation.

On attempting to decide upon the proper name to be applied to the valley shales, much difficulty is encountered, and it becomes necessary to try to understand the conditions under which sedimentation took place. The beginning of the Miocene in the California region was a period of very violent crustal movements and great change of climate. A land mass to the west of the present coast line appears to have arisen and all but shut off a great inland sea dotted here and there with islands. Remnants of such a land mass may be seen in the Farallones Islands and the Point Reyes peninsula. The climate became increasingly arid later in the Miocene so that less and less sediment was washed from the land into the quiet waters. Such sediment as did come in was dropped at the mouths of streams near shore and formed fan-shaped deposits. In these appeared characteristic faunas of higher organisms such as the mollusks and echinoids, but the deposits were of comparatively short life in most places, due to fluctuation in rainfall and local oscillation of the shore lines. Consequently, there was an ever changing littoral fauna. These littoral deposits with their varied faunas have since been exposed, and due to their dissimilarity, they have been given different formational names. Attempts to correlate one with the other have not met with general approval. Local unconformities and disconformities have been confusing to geologists who have been loath to consider many of them as exactly

equivalent in age. This is particularly true in regard to the several basins of deposition in the ancient sea.

But while inshore conditions were thus subject to great changes, throughout the Miocene the bathymetric conditions were remarkably constant. The freedom of the water from any considerable amount of clay or other fine sediment produced an environment admirably suited to the growth of micro-organisms, and a large and varied fauna and flora flourished undisturbed. Their remains "rained" down to the bottom and produced an almost colloidal sludge, in which the heavier mollusks would smother.

So abundant were the micro-organisms and so long the period of accumulation of their remains that very thick deposits were made. Rainfall was so slight that in many places the bottom was covered with the minute remains of organisms practically up to the shore lines. In the locality of Chico-Martinez Creek, over 8,000 feet of such sediment was deposited without a single important break in sequence. Wherever found today these sediments are easily recognized by their characteristic thinly bedded structure and light colors.

Thus organic shales were being formed throughout the period of the Miocene, and the sandy inshore sediments are merely local phases. Louderback in 1913,[1] in a masterly analysis of the same problem reached the same conclusion. For that reason he adopted the name "Monterey" to express a group just as Lawson had previously done. He attached no more importance to the inshore sandstone layers than that they were mere local phases of sedimentation.

It happens that in the near vicinity of the town of Monterey such sandy layers are rare and the mass of the deposit is organic shale. While some of this shale was being deposited there, sands were being laid down locally elsewhere which doubtless may require local names for distinction and separate designation. They form, however, an integral portion of the Monterey group. Such usage, it appears, would not invalidate the use of the name "Monterey shale" to designate the shales similar to those which were being deposited contemporaneously at Monterey.

[1] G. D. Louderback, *Univ. Cal. Publ. Geol.*, Vol. 7, No. 10 (1913), pp. 177, 241.

From the paleontologic study which has been made, there is every reason to believe that the upper 4,000 feet of the shale in the southern part of the San Joaquin Valley, usually called "Maricopa shale," is equivalent in age to the shale at Monterey. It is equally clear that the section at Monterey is incomplete and the basal layers were not there deposited. Probably the underlying granite at Monterey formed a portion of the westward land mass during the early part of the Miocene. Nevertheless, the complete record of deposition of sediment during the period was preserved elsewhere and does not invalidate the use of the name "Monterey."

Many other names have been applied to these characteristic Miocene shales in California, and if making "Monterey" a group-name prevents the use of the term "Monterey shale," then, according to the rules, the first name subsequently given must be revived. Before making a search of the literature to ascertain which name could thus be used, it seems desirable to secure the opinions of other geologists as to the availability of "Monterey shale." Under all circumstances the name "Maricopa" seems to be inapplicable because it is one of the last to have been proposed.

On account of the proximity of oscillating shore lines, local unconformities make it very difficult to subdivide the great body of shale on stratigraphic evidence. Also the deposition of local sands here and there and at various times makes correlation based upon the lithology of them very insecure. The only broad and general phase of sedimentation during the period is that displayed in the shales which accumulated continuously off shore. From the studies which have thus far been made of them it appears that convincing paleontologic evidence can be presented to show that there was considerable variation in the faunas and floras in different parts of the period and, owing to uniformity of conditions, these parts can be correlated, one with the other. At this time, however, it would be premature to venture to subdivide the shale on this basis. Eventually it will probably be possible to determine which part of the shale corresponds in age to interbedded sandy shale deposited elsewhere.

The illustrations of the diatoms (Plates 4 and 5) shown herewith were furnished by Mr. William M. Grant, of San Francisco.

PLATE 4*

Characteristic Diatoms of the Upper Part of Monterey Shale

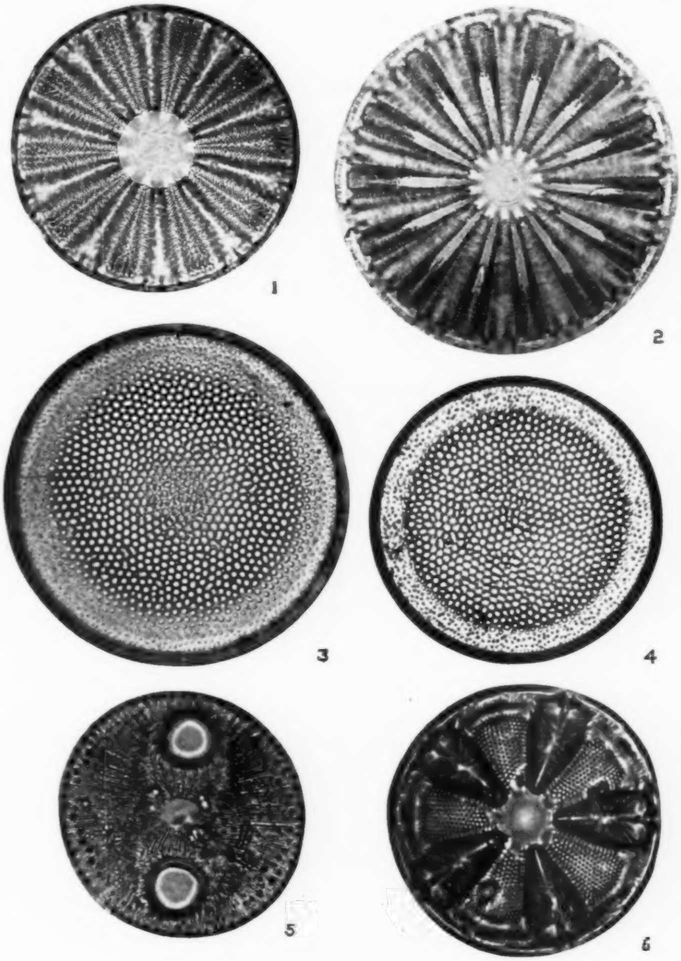
Fig. 1.—*Actinoptychus glabratus*, var.; enlarged 340 diameters. Fig. 2.—*Actinoptychus glabratus incisa* Grunow; enlarged 210 diameters. Fig. 3.—*Coscinodiscus incretus* A. Schmidt; enlarged 270 diameters. Fig. 4.—*Coscinodiscus incretus* A. Schmidt; enlarged 226 diameters. Fig. 5.—*Auliscus stockhardtii* Janisch; enlarged 452 diameters. Fig. 6.—*Actinoptychus* sp. (?); enlarged 725 diameters.

PLATE 5

Characteristic Diatoms and Radiolarians of the Upper Part of Monterey Shale

Fig. 1.—*Stictodiscus californicus ecostatus* Grunow; enlarged 300 diameters. Fig. 2.—*Arachnoidiscus ornatus montereianus* A. Schmidt; enlarged 200 diameters. Fig. 3.—*Melosira clavigera* (?) Grunow; enlarged 465 diameters. Fig. 4.—*Triceratium validum* Grunow; enlarged 330 diameters. Fig. 5.—A group of diatoms and radiolarians; the first, third, fourth, and fifth in the upper row and all of the second row are radiolarians; the remainder are diatoms; enlarged 72 diameters.

* We are under obligation to Dr. Albert Mann, of the Carnegie Institution, Washington, D.C., for the identification of the diatoms shown in Figs. 2 and 5 of Plate 4 and Figs. 1 and 3 of Plate 5.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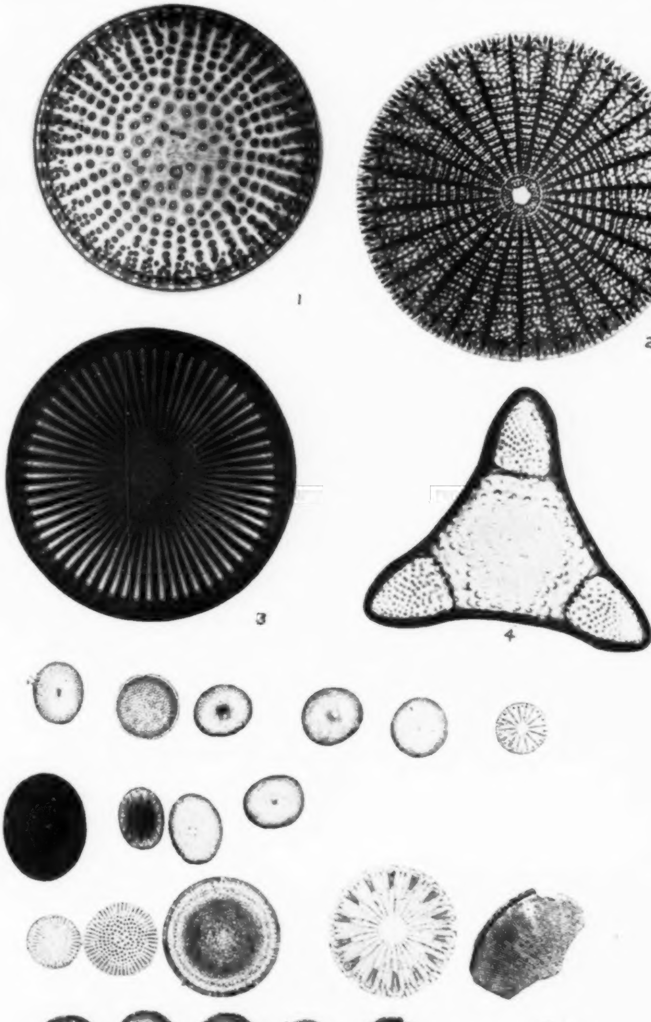
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ANALYSES OF WYOMING OIL-FIELD WATERS[1]

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ABSTRACT

In general, waters in Wyoming oil fields show a tendency toward a reduction in sulphate content and increase in carbonate and chlorine content and general concentration with increasing depths unless the waters have been modified by circulation. Secondary salinity decreases with depth, and in cases of deeper sands disappears altogether.

The Dakota sand waters show a content of sulphate at greater depths than the Frontier sand waters, due to more rapid water circulation and general replenishment of sulphates to the deeper waters.

In Wyoming fields, waters in contact with oils show a tendency toward the reduction of sulphates and increase in carbonates. Oils in contact with underground waters are altered and show a reduction in lighter fractions which results in lower-gravity oil. The Salt Creek field shows alteration of the oil in a zone extending from 100 to 150 feet above the water line. In the Big Muddy field, the oil appears to be altered over the entire producing area, probably due to rapid water circulation which is shown by the high sulphate content of the water, tilted water table, and nearness of outcrops.

The analyses of water samples from the oil fields of Wyoming were begun by the Midwest Refining Company in 1920. The analyses given in this paper were made in the Casper Laboratory of the Standard Oil Company of Indiana under the direction of Dr. S. K. Loy, chief chemist. Water samples are taken, as far as possible, by or under the personal supervision of a representative of the production-engineering office and delivered by him to the laboratory, special care being taken to determine the exact source of the water and to assure the purity of the sample. Glass bottles have proved to be the most satisfactory containers because of the ease with which their cleanness is assured and the length of time a sample can be preserved without deterioration. The analyses are worked out in the laboratory according to Palmer's[2] classification, and recorded on the form shown in Figure 1.

[1]Read before the Association, Shreveport meeting, March, 1923. Manuscript received by the Editor, January 10, 1925.

[2] Chase Palmer, "The Geo-Chemical Interpretation of Water Analyses," *U. S. Geol. Surv. Bull. 479*, 1911.

The work on the analyses and interpretation of the oil-sand waters of Wyoming has already proved its value in aiding in the solution of water problems in the producing fields, and is being put to practical use. It is expected that eventually some light will be thrown upon the problem of the conditions of oil accumulation, especially

THE MIDWEST REFINING COMPANY

WATER ANALYSIS

Field ________ Lease ________ Well No. ________
Sample from ________ Sand at Depth ________ to ________ Date ________
Sample taken by ________ Method ________
Analyst ________ Date ________ Laboratory No. ________

Compounds 1	Grains Per U. S. Gallon 2	Parts Per Million (2) x 17.12 3	Factor 4	Positive Radicles (3) x (4) 5		Negative Radicles (3) − (5) 6		Constituents in Grams Per Liter
Na_2SO_4			.324	Na		SO_4		SiO_2
NaCl			.393	Na		Cl		Al_2O_3 and Fe_2O_3
Na_2CO_3			.434	Na		CO_3		CaO
Na_2S			.589	Na		S		MgO
$CaSO_4$			.294	Ca		SO_4		Na_2O
$CaCl_2$			.361	Ca		Cl_2		
$CaCO_3$			.400	Ca		CO_3		SO_4
$MgSO_4$			.202	Mg		SO_4		Cl
$MgCl_2$			.255	Mg		Cl_2		CO_3
$MgCO_3$			.288	Mg		CO_3		Volatile
								Total Solids

REACTING VALUES

	Na	Ca	Mg		SO_4	Cl	CO_3	S
Total (a)								
Reaction coeff (b)	.0435	.0499	.0822		.0208	.0282	.0333	.0624
(a) x (b)								
								Total (a x b) =
Reacting value %								

PROPERTIES OF REACTION IN PER CENT

PRIMARY SALINITY: SO_4 + Cl = ________, with equal value Na (K) ________ = ________%
SECONDARY SALINITY: If SO_4 + Cl is greater than Na (K) ________ = ________%
Then SO_4 + Cl = ________ with equal value of Ca + Mg ________ = ________%
PRIMARY ALKALINITY: Excess Na (K) over SO_4 + Cl = ________ with equal value of CO_3 + S ________ = ________%
SECONDARY ALKALINITY: Excess Ca + Mg over SO_4 + Cl = ________ with equal value of CO_3 + S = ________%
100%
CHLORIDE SALINITY: Cl ÷ (SO_4 + Cl) = ________ x 100% = ________
SULPHATE SALINITY: SO_4 ÷ (SO_4 + Cl) = ________ x 100% = ________

NORMAL CARBONATES: Calculated as $CaCO_3$ ________ parts per million
BICARBONATES: Calculated as $CaCO_3$ ________ parts per million

REMARKS:

FIG. 1

in reference to the possible "flushing" of the oil through the sands by moving waters. Much remains to be done, not only in increasing the number of analyses available, but especially by widening the scope of the investigation and securing samples from the same sands under a wide variety of geologic conditions. The character of the water in a sand may be expected to show a considerable lateral vari-

ation as influenced by its association with oil; by varying porosity in the sand which affects the circulation of water; by its position relative to the outcrops where surface water enters the sand; and by its structural position which protects it from or exposes it to the currents of underground circulation.

GENERAL CHARACTER OF THE WATERS

The typical surface waters of central Wyoming are characterized by high percentages of sulphates and by marked secondary salinity or permanent hardness. A representative analysis of a river water is shown in analysis No. 1 (see Table I) and of a spring water from the subsoil in No. 2. The secondary-salinity ratio is much lower in the spring water than in the river water, and in all deeper waters disappears entirely, except under very unusual conditions. Analysis No. 23 is from a water well drilled through the Dakota and Lakota sands of the Dakota group, about 4 miles from their outcrop along the flanks of the Black Hills in eastern Wyoming. These sands are relatively porous and permit a widespread circulation of only slightly altered surface waters. They both contain numerous particles of iron sulphide, the alteration of which may have supplied the acid necessary to reduce the carbonate content to zero.

Slightly modified ground waters, as classified by Rogers,[1] are represented by Nos. 3, 20, 22, and 24. No. 22 from the Mule Creek field is a deep-sand water in contact with oil and yet has a high sulphate content. The explanation is probably that the sulphate is being constantly renewed by circulation from the outcrop 10 miles distant. Under such conditions the interreactions of the oil and water proceed far enough to make important changes in the character of the oil. In analyses Nos. 3, 20, and 24, from shallow water sands, the secondary salinity of the normal surface waters has been replaced by an average primary alkalinity ratio of 57.4 per cent. The average concentration has risen from 0.7997 to 2.1412 grams per liter. The proportion of the sulphate to the carbonate ratio is about 1 to 3.

More completely modified waters are Nos. 4, 5, 6, 7, and 8 from

[1] G. S. Rogers, "Chemical Relations of the Oil Field Waters of the San Joaquin Valley, California," *U. S. Geol. Surv. Bull. 653*, 1917.

TABLE I

Analyses of Wyoming Oil-Field Waters

	1	2	3	4	5	6	7	8	9	10	11	12
	Constituents in Grams per Liter											
SiO_2	.0044	.0014	.0968	.0001	.0325	.01540	.0220	.0450	.0145	.0292	.004	....
Fe_2O_3 and Al_2O_3	.0047	.0054	.0455	.0399	.0507	.03020	.4768	.0323	.1361	.0236	.0080	.0075
CaO	.0462	.1078	.0543	.0402	.0417	.0523	.7080	.2663	.1870	.0185	.1844	.0101
MgO	.0154	.0555	.1000	.0786	.1060	.0319	.0210	.1142	.0916	.0174	.0692	.0046
Na_2O	.0289	.3860	1.0424	1.4676	1.2556	1.38160	4.0030	1.4663	4.3624	3.8173	10.3565	2.0030
SO_3	.0568	.5282	.3975	.2069	.0462	.1868	.4085	.1377	.3033	.0246	.0181	.0714
Cl	.0070	.0142	.0174	.2045	.0873	.05230	.1290	.0943	.4648	1.0700	10.0000	.3480
Loss	.0583	.2791	.2331	.2175	.0605	.1407	2.1520	.0712	3.6663	2.6606	2.5926	1.5606
Total solids	.2217	1.3776	1.9870	2.2553	1.6805	1.8912	7.9203	2.2273	9.2260	7.6612	23.2328	4.0052
	Reacting Values in Percentages											
Na	13.93	32.68	40.9	44.9	42.8	46.4	41.6	37.9	46.3	49.4	48.5	49.6
Ca	24.64	10.10	2.9	1.3	1.5	2.0	8.1	7.5	2.2	.3	1.0	.3
Mg	11.43	7.22	6.2	3.8	5.7	1.6	.3	4.6	1.5	.3	.5	.1
SO_4	21.20	34.57	12.7	4.8	1.2	4.9	3.3	2.7	2.5	.2	.1	1.4
Cl	2.95	1.05	.6	5.5	2.5	1.5	1.2	2.1	4.3	12.2	42.4	7.6
CO_3	25.85	14.38	36.7	39.7	46.3	43.6	45.5	45.2	43.2	37.6	7.5	41.0
Primary salinity	27.86	65.36	26.6	20.6	7.4	12.8	9.0	9.6	13.6	24.8	85.0	18.0
Secondary salinity	20.40	5.88	....	....	....	....	....	....	....	....	....	....
Primary alkalinity	....	....	55.2	69.2	78.2	80.0	74.2	66.2	79.0	74.0	12.0	81.2
Secondary alkalinity	51.74	28.76	18.2	10.2	14.4	7.2	16.8	24.2	7.4	1.2	3.0	.8
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Chloride salinity	12.20	2.95	4.5	53.4	67.5	23.4	26.7	43.8	63.3	98.4	99.8	84.4
Sulphate salinity	87.80	97.05	95.5	46.6	32.5	76.6	73.3	56.2	36.7	1.6	.2	15.6

NOTES TO TABLE I

1. Platte River at Yellowstone Bridge, Casper.
2. Spring 10 miles north of Salt Creek field.
3. Big Muddy field; A. E. Humphrey well No. 12; water sand; depth, 260–75 feet.
4. Big Muddy field; R. B. Whiteside well No. 12; Shannon sand; depth, 960–1,010 feet.
5. Big Muddy field; I. B. Humphrey well No. 1; First Wall Creek sand; depth, 3,418–28 feet.
6. Big Muddy field; Pool No. 2; First Wall Creek sand; depth, 3,268–80 feet.
7. Big Muddy field; Merritt well No. 1; First Wall Creek sand; depth, 3,316–38 feet.
8. Big Muddy field; Whiteside 2 well No. 2; First Wall Creek sand; depth, 3,100–3,200 feet.
9. Big Muddy field; Elkhorn well No. 11; First Wall Creek sand; depth, 2,998–3,088 feet.
10. Big Muddy field; Glenrock Sheep well No. 28; First Wall Creek sand; depth, 3,062–65 feet.
11. Big Muddy field; S. A. Smith well No. 5; First Wall Creek sand; depth, 3,232–44 feet.
12. Salt Creek field; NW. ¼ NE. ¼ 8-39-78 well No. 18-A; First Wall Creek sand; depth, 2,275–2,345 feet.

TABLE I—*Continued*

	13	14	15	16	17	18	19	20	21	22	23	24
	Constituents in Grams per Liter											
SiO_2	....	.1612	....	.0020	.0016	.0216	.0040	.0407	.1289	.0358	.0127	....
Fe_2O_3 and Al_2O_3	.0123	.0210	....	....	.0054	.0220	....	.0394	.3287	.0288	.0370	....
CaO	.0171	.0296	Trace	.0094	.0256	.0138	.0138	.0995	.0244	.0494	.1189	.0580
MgO	.0085	.0514	Trace	.0087	.0107	.0070	.0078	.0111	.0439	.0114	.0960	.0345
Na_2O	3.3330	5.4820	1.3000	2.4322	6.3500	1.5637	2.1562	1.5248	.3564	.2822	.2985	.5390
SO_3	.0263	.0192	....	.0028	.0390	....	.0140	.3184	.0209	.0647	1.0684	.2130
Cl	.5946	1.9620	.0260	.3360	4.3430	.1680	1.2995	.1524	.0137	.0105	.0042	.0700
Loss	2.4618	3.4700	1.3240	1.7403	1.5387	.9631	.7334	1.0297	.0198	.1357	.0488	.3690
Total solids	6.4536	11.1964	2.6500	4.5314	12.3140	2.7592	4.2287	3.2160	.9367	.6185	1.6845	1.2205
	Reacting Values in Percentages											
Na	49.5	49.0	50.0	49.54	49.7	49.2	49.50	46.2	39.1	39.9	26.0	41.0
Ca	.3	.3	....	.20	.2	.5	.28	3.3	3.4	7.5	11.2	5.0
Mg	.2	.7	....	.26	.1	.3	.22	.5	7.5	2.6	12.8	4.0
SO_4	.3	.1	....	.04	.2	....	.24	7.5	1.7	7.0	49.7	12.5
Cl	7.7	15.4	0.8	5.98	29.6	4.6	26.04	4.0	1.4	1.3	.3	4.7
CO_3	42.0	34.5	49.2	43.98	20.2	45.4	23.72	38.5	46.9	41.7	....	32.8
Primary salinity	16.0	31.0	1.6	12.04	59.6	9.2	52.56	23.0	6.4	16.6	52.0	34.4
Secondary salinity	....	....	....	....	....	....	....	....	....	....	48.0	....
Primary alkalinity	83.0	67.0	98.4	87.04	39.8	89.2	46.44	69.4	71.8	63.2	....	47.6
Secondary alkalinity	1.0	2.0	....	.92	.6	1.6	1.00	7.6	21.8	20.2	....	18.0
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Chloride salinity	96.25	99.4	100.0	99.40	99.4	99.9	99.3	34.7	45.0	15.7	.6	27.3
Sulphate salinity	3.75	.6	....	.60	.6	Trace	.7	65.3	55.0	84.3	99.4	72.7

NOTES TO TABLE I

13. Salt Creek field well No. 36-A; SE. ¼ 13-40-79; First Wall Creek sand; depth, 1,735-1,845 feet.
14. Salt Creek field well No. 29-A; NE. ¼ 24-40-79; First Wall Creek sand; depth, 1,220 feet.
15. Salt Creek field well No. 2; SE. ¼ 11-39-79; First Wall Creek sand; depth, 1,865-2,055 feet.
16. Salt Creek field well No. 2—Norris; SE. ¼ 19-40-78; First Wall Creek sand; depth, 2,110-2,312 feet.
17. Salt Creek field well No. 12-A; SW. ¼ 3-39-79; Second Wall Creek sand; depth, 2,065-3,030 feet.
18. Salt Creek field well No. 7-A; SE. ¼ 25-40-79; Lakota sand; depth, 2,570-2,600 feet.
19. Midway Dome well No. 1; NE. ¼ 23-35-79; Shannon sand; depth, 2,430-80 feet.
20. Mule Creek field well No. 1; NE. ¼ SE. ¼ 25-39-61; Water sand; depth, 400 feet.
21. Mule Creek field well No. 45; 19-39-60; Dakota sand; depth, 1,200 feet.
22. Mule Creek field well No. 2; NW. ¼ SW. ¼ 19-39-60; Lakota sand; depth, 1,424-35 feet.
23. Osage field well No. 1; SE. ¼ 11-46-64; Dakota and Lakota sand; depth, 1,705-1,814 feet.
24. Salt Creek field well No. 1; SW. ¼ 20-40-78; Shannon sand; depth, 395-440 feet.

the Big Muddy field. These are bottom waters pumped with the oil. No. 4 is from the Shannon sand, and the others are from the First Wall Creek, which is the principal producing sand of the field. The concentration rises, in these deeper waters, to an average of 3.1949 grams per liter, and the primary alkalinity goes up to 73.6 per cent. The proportion of sulphate to carbonate is about 1 to 13. Big Muddy field presents another case where the sulphate content of the oil-sand water is being renewed by circulation from the outcrop, and its continued presence has resulted in a notable modification of the oil.

In sands where a lack of uniform porosity, structural position, or distance from the outcrop prevents the replenishment of the sulphates by fresh surface waters entering the sand, the waters in contact with the oil have their sulphate content reduced almost to zero, probably by reaction with the hydrocarbons. These altered waters, the "reversed" type of Rogers,[1] are represented by analyses Nos. 9, 10, 12, 13, 15, 16, and 18. In these analyses the sulphate reacting value averages only 0.6 per cent, while the carbonate is 43.2 per cent, a proportion of 1 to 69. The primary alkalinity rises to an average of 84.6 per cent and the concentration to 5.3263 grams per liter. The chloride ratios in these waters are more than double those in the surface and shallow waters.

The large chloride ratio and high concentration of sample No. 11 suggests that it may be a connate water, somewhat altered by contact with oil. No. 14 is a bottom water associated with oil in the First Wall Creek sand in the Salt Creek field. The greater concentration of this water, as compared with No. 13, representing water from the same sand at a distance from production, strongly suggests the influence of evaporation by escaping gases, as suggested by Mills and Wells.[2]

Samples Nos. 17 and 19 are similar in general character, except that No. 19 is comparatively dilute. No. 17 is edge water in the Second Wall Creek sand at Salt Creek, taken from a point only a few hunderd feet away from the oil. No. 19 is from the Shannon sand which

[1] G. S. Rogers, *op. cit.*

[2] R. V. A. Mills and R. C. Wells, "The Evaporation and Concentration of Waters Associated with Petroleum and Natural Gas," *U. S. Geol. Surv. Bull. 693*, 1919.

occurs some 2,500 feet stratigraphically above the Second Wall Creek. The sample was taken on top of a closed anticlinal fold, and was associated with a small show of gas but with no oil. The depth below the surface is about the only feature of occurrence which is common to both samples. This suggests a tendency which has been noted in a few other cases of the chlorides to increase with depth when the character of the waters has not been modified by circulation from the outcrop or by the escape of associated gases.

Sample No. 21 is a very dilute water, lying in general character between the modified and the altered waters. Its low concentration is thought to be due partly to rapid circulation and partly to the fact that the Dakota is a cleaner, purer sand than is the Wall Creek, and the water has had less opportunity to load itself up with dissolved solids from minerals with which it has been in contact.

ASSOCIATION WITH OIL OF THE WATERS SAMPLED

Samples Nos. 4, 5, 6, 7, 8, 9, 11, 18, and 22 were produced with oil from oil wells. Nos. 1, 2, 3, 20, and 23 have probably never been in contact with oil. Nos. 10, 14, and 17 are edge waters from oil-bearing sands a few hundred feet outside of the oil pool. Nos. 12, 13, 15, and 16 are from a sand which produces oil at distances of from ½ to 2½ miles away from the wells in which the samples were obtained. Nos. 19 and 24 were taken 5–20 miles from the nearest known oil accumulation in the sand. No. 21 is associated with small showings of oil.

WATERS OF BIG MUDDY FIELD

The changes in the underground waters with increasing depth are well shown by the series of samples Nos. 1, 3, 4, and 5 from the Big Muddy field. No. 1 is from the river which flows beside the field; No. 3 is from a sand at 275 feet; No. 4 is from 1,000 feet; and No. 5 from 3,400 feet in depth. The total solids show a large increase from the surface to the First sand, a smaller increase in the Shannon at 1,000 feet, and then decrease in the First Wall Creek sand, at 3,400 feet. The small amount of solids in this First Wall Creek sample is thought to be due to the dilution of the normal deep-sand water by infiltration from the sand outcrop a few miles away. The sulphates decrease with depth and are replaced by carbonates.

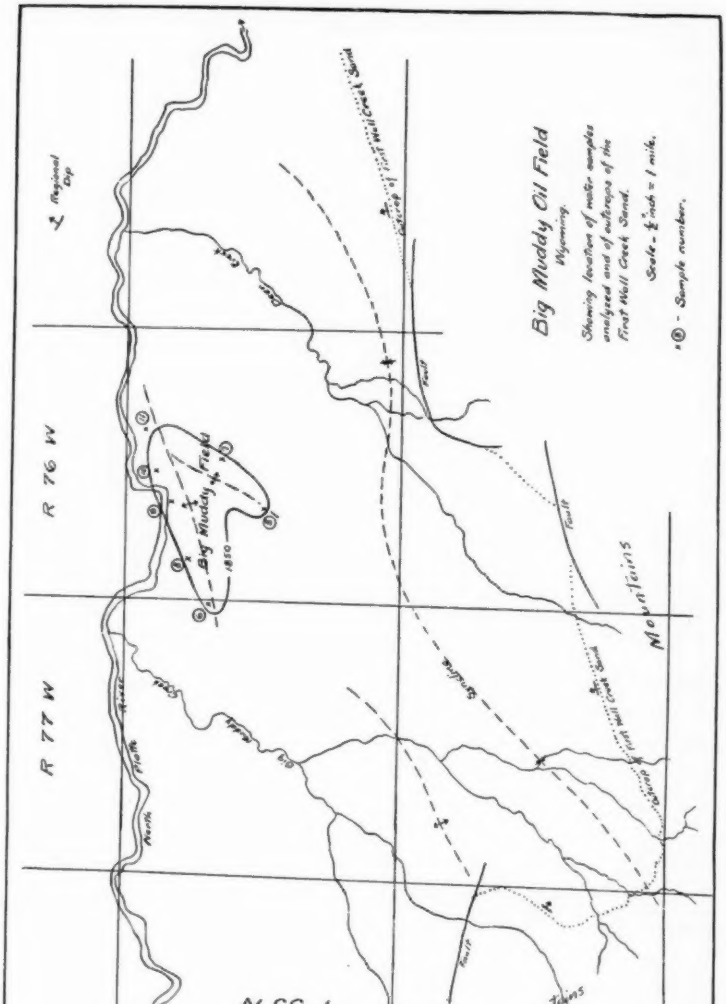
Big Muddy Oil Field
Wyoming.
Showing location of water samples analyzed and of outcrops of the First Wall Creek Sand.
Scale – ½ inch = 1 mile.
Sample number.
R 77 W
R 76 W
T 33 N
Regional Dip
Big Muddy Field
1850
North Platte River
Fault
Mountains

FIG. 2

The presence of sulphates in the Big Muddy waters in contact with oil—Nos. 4, 5, 6, 7, 8, 9, and 11—is thought to be due to infiltration of surface water at the outcrops a few miles away. Figure 2 shows the position of the outcrops and the location on the anticline of the wells from which water samples were obtained. The direction of underground circulation is probably to the north and east toward points of outcrop at a lower surface elevation.

The movement of the water eastward along the north flank of the Big Muddy anticline is shown by the increased concentration of waters Nos. 10 and 11 over Nos. 6 and 8, and by the fact that the oil-water contact is tilted downward toward the east. The water line in the vicinity of sample No. 11 is more than 100 feet lower than at sample No. 6. The eastward movement of the water has "dragged" the oil with it and produced a tilted water table. Samples Nos. 7, 9, 10, and 11 are less exposed to the water currents (if so slow a movement may be termed a "current"), and are much more concentrated waters than Nos. 5, 6, and 8.

DIAGRAM FOR PLOTTING ANALYSES

The triangular diagram used by Rogers[1] to show the proportions of the acid radicles is helpful as a quick and convenient guide in classifying the analyses (Fig. 3). The changes that are associated with increasing depth carry the analyses from the top, down along the left side of the diagram, and then with greater concentration across from left to right along the base of the triangle. Analyses Nos. 24, 4, and 19, from the Shannon sand, show these changes in the proportion of the acid radicles as the depth and concentration increase.

ALTERATION OF OIL BY EDGE WATER

The Salt Creek and Big Muddy oil fields are located about 50 miles apart along the southwest side of the great synclinal basin between the Black Hills and the Big Horn Mountains. Their axes are about at right angles and the folds may have been formed at different periods and as a result of entirely different stresses. Oil is produced in both fields from the first sand of the Frontier formation, and although the general geologic conditions are very similar, the

[1] G. S. Rogers, "The Sunset-Midway Oil Field, California," Part II, *U. S. Geol. Surv. Prof. Paper 117*, p. 60.

two oils show a considerable difference. The analyses given below are by the United States Bureau of Mines.[1]

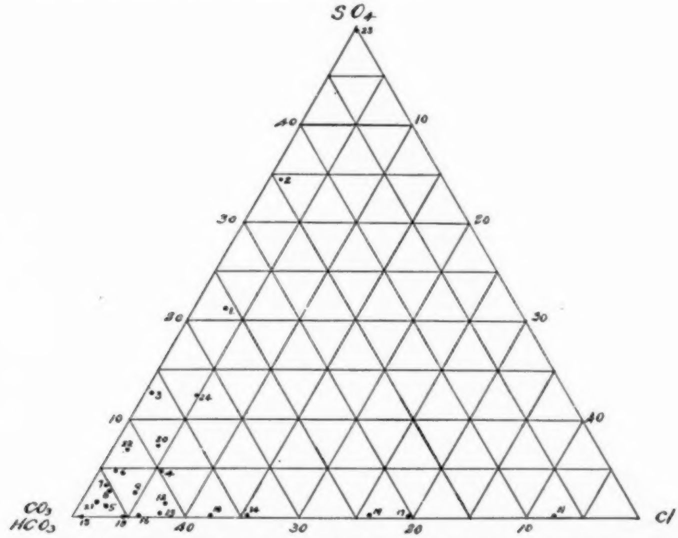

FIG. 3.—Diagram showing portions of sulphate, carbonate and bicarbonate, and chloride in Wyoming oil-field waters. The portions of each constituent are plotted in percentages reacting values. The numbers refer to analyses.

TABLE II

	SALT CREEK			BIG MUDDY		
	Percentage	Sp. Gr.	° Bé.	Percentage	Sp. Gr.	° Bé.
Crude oil	....	.841	36.5	....	.863	32.2
Gasoline	29.3	.750	56.7	22.2	.762	53.7
Kerosene	15.7	.824	39.9	15.7	.832	38.3
Gas oil	10.8	.847	35.5	9.0	.860	32.8
Lt. lub. dist	11.1	.865	31.9	11.1	.877	29.6
Med. lub. dist	5.8	.880	29.1	5.9	.890	27.3
Carbon residue	....	....	....	....	....	....
Residuum	6.1	....	....	6.0	....	....
Sulphur in cr	0.18	....	....	0.17	....	....
Initial boiling-point	First drop, 25° C. (77° F.)			First drop, 58° C. (136° F.)		

[1] E. W. Dean, "Properties of Typical Crude Oils from the Producing Fields of the Rocky Mountain District," *U. S. Bur. Mines Serial 2235*, April, 1921.

The analyses show the two oils to be very similar, except that the Big Muddy crude contains a smaller percentage of gasoline. It appears to be an altered crude of the same original character as the Salt Creek oil. Oils showing a similar type of alteration occur close to the water line in both the First and Second sand pools at Salt Creek but the great body of crude in that field is of the type shown in the foregoing analysis. The character of an edge oil in Salt Creek, as compared to an average oil in the center of the pool, is shown in the following analyses:

TABLE III

	Salt Creek, Second Wall Creek Sand	
	Edge Oil	Average Oil
Gravity	31.5	37.7
Initial boiling-point	210	130° F.
Percentage off at 214° F. (sea-level)	0.4	2.0
Percentage off at 221° F. (sea-level)	1.0	7.4
Percentage off at 284° F. (sea-level)	7.0	16.4
Percentage off at 374° F. (sea-level)	17.2	27.2
Percentage off at 400° F. (sea-level)	20.0	40.6
Percentage off at 550° F. (sea-level)	40.0	54.0
Percentage off at 700° F. (sea-level)	65.6	69.6

The alteration of the oil in Salt Creek seems to be limited to a zone extending 100–150 feet structurally above the water line. At Big Muddy it extends over the entire pool or to a structural height of about 150 feet.

The water analyses from Salt Creek and Big Muddy indicate that part or all of the alteration of the oil is due to the presence of sulphate in the surrounding water in contact with the oil. At Big Muddy the edge water—analyses Nos. 5, 6, 7, 8, 9, and 11—show an average sulphate reacting value of 2.4 per cent, while at Salt Creek the average is probably less than 0.5 per cent. The data concerning the sulphate content of Salt Creek water are contradictory. Flowing water wells from the First sand show no sulphate or only a trace, while water from wells which do not flow is so often contaminated by the sulphate-bearing water that has been put into the hole during drilling operations that the analysis cannot be depended upon for exactness as to sulphate content, but Wegemann[1] found

[1] C. H. Wegemann, "The Salt Creek Oil Field, Wyoming," *U. S. Geol. Surv. Bull. 670*, pp. 42–44.

some sulphate in water being produced with the oil from the First sand, and his data were checked by Heald[1] in 1921 as to the sulphate content of water obtained from well No. 7, SW. $\frac{1}{4}$ 13-40-79. The explanation may be that the upper bench of the First sand[2] contains more sulphate than does the lower bench where the artesian water is found, and that the water tested by Wegemann and Heald is predominantly from the upper bench. The few analyses that have been made of water from the Second Wall Creek sand at Salt Creek indicate a very low sulphate content.

The less extensive alteration of the oil in Salt Creek may be partly due to the less rapid circulation of the surrounding water. At Big Muddy the high sulphate content of the water, the tilting of the water table, and the nearness of the outcrops, all indicate a more rapid circulation than occurs at Salt Creek.

Further evidence of this alteration of crude oil by reduction of its lighter fractions is afforded at Mule Creek, Wyoming. The water —analysis No. 22—contains sulphate to 7 per cent reacting value. The analysis of the oil by the United States Bureau of Mines[3] is as follows: gravity of crude, 31.5° Baumé, gasoline, 11.7 per cent; kerosene, 17.4 per cent; gas oil, 13.1 per cent; light lubricant distillate, 31.1 per cent; medium lubricant distillate, 7.4 per cent; carbon residue residuum, 4.8 per cent. No unaltered oil exists with which the Mule Creek crude may be compared unless we use the nearest other occurrence of oil in the sands of the Dakota group, Lance Creek, Wyoming, where the oil has a gravity of 40.1° Baumé, gasoline, 33.5 per cent; kerosene, 16.2 per cent; gas oil, 11.3 per cent; light lubricant distillate, 10.7 per cent; medium lubricant distillate, 6.0 per cent; carbon residue residuum, 2.0 per cent.[4] Possibly the explanation of the wide difference in the oils being produced from the sands of the Dakota group, oils varying from 30.0° Baumé at Lost Soldier to 49.3 Baumé at Cat Creek, Montana, may be found in the character of the surrounding waters and the rapidity of their circulation.

[1] K. C. Heald, private communication to C. H. Wegemann.

[2] K. B. Nowels, "Preliminary Report on Water Conditions in the First Wall Creek Sand, Salt Creek Oil Field, Wyoming," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8 (July-August, 1924).

[3] E. W. Dean, *op. cit.*

[4] *Ibid.*

A CONTRIBUTION TO THE ORIGIN OF THE GREEN RIVER FORMATION AND ITS OIL SHALE[1]

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ABSTRACT

As a result of the writer's field work on the Green River formation, and his study of the microfossils of the oil shale and of the analogy of the shale with the deposits of modern lakes, there appears to be the following trend in the formation's geologic history: The Green River lakes were formed as relatively stable, shallow, fresh-water bodies; under climatic influence they gradually changed to lakes that periodically filled and evaporated but that supported a luxuriant microflora. In the third stage they became quite strongly alkaline ponds, perhaps playa-like, in the muds of which considerable glauberite crystallized out. In the shallow, expanding and contracting fresh or mildly alkaline lakes of the intermediate stage organic ooze consisting almost wholly of plankton organisms (dominantly microscopic algae) accumulated in large quantities. Bacteria caused active putrefaction of the ooze and evaporation reduced the decaying mass to a syrupy consistency or occasionally to actual dryness. This macerated organic matter was covered by the deposits of the next cycle and subsequently lithified into oil shale.

INTRODUCTION

Junius Henderson's paper[2] on the origin of the Green River formation published in a recent issue of this *Bulletin* is a stimulating discussion of a subject in which the present writer is keenly interested, inasmuch as he has had the opportunity with the United States Geological Survey, since the summer of 1922, of devoting his entire attention in the field and in the office to that study.

In the course of this study new evidence has been obtained which may assist in the interpretation of the Green River formation and its oil shale. Although these new data neither solve the problem in its entirety nor remove all the paradoxes, they appear to the writer to offer some sound working hypotheses for further investigation and observation, and as such they are presented here.

ACKNOWLEDGMENTS

The writer takes this opportunity to express his thanks to Dr. W. F. Foshag, of the National Museum, for his examination of the

[1] Published by permission of the Director, U. S. Geological Survey.
NOTE.—See supplementary statement on p. 410.

[2] Junius Henderson, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 5 (1924), p. 662.

salt-crystal molds mentioned in this paper, and to Dr. J. D. Sears, of the Survey, for his helpful criticism of the manuscript.

SUMMARY OF GEOLOGIC HISTORY

It might be well to offer in advance an outline of the history of the Green River formation as seen by the writer in the light of recent observations. With this outline as a framework, the relations and significance of the evidence to be presented should be more readily understood. In the broad, shallow Uinta and Green River basins were initiated essentially permanent fresh-water lakes which fluctuated but little in volume under a seasonal but withal quite warm and moist climate. As sedimentation continued, the basin floor was warped downward and could hold a larger volume of materials. The climate gradually changed; the rainy seasons became shorter and alternated with periods of pronounced drought. This resulted in alternate flooding and complete or partial evaporation of the lakes, a condition under which the beds of oil shale accumulated. As a closing phase of this history, the periods of drought became longer and more accentuated until under essentially arid climatic conditions the lake basins became playa-like and such salts as glauberite crystallized out in the muds. As the sediments reflected the climatic conditions, these three climatic stages of Green River time correspond more or less closely to the three lithologic members of the Green River formation. The lithology and fossils of each of these members are significant in showing the conditions under which the formation and its oil shale accumulated.

So far as the writer is aware, there is little if any actual proof that the three lithologic members of the Green River formation in the Green River Basin correlate exactly with the three lithologic members of that formation in the Uinta Basin. However, they do have remarkably similar lithology in these two closely adjacent basins, and for that reason alone the writer is treating them in this general discussion as correlative units of the same formation.

BASAL MEMBER OF THE GREEN RIVER FORMATION

LITHOLOGY

This member includes all the rocks between the variegated clay of the Wasatch formation and the base of the middle or oil-shale

member of the Green River. In Wyoming and northwestern Colorado this basal member is mapped either as the Tipton shale member or the Tipton tongue of the Green River formation, depending upon its relations with the Wasatch formation. These relations on the south side of the Green River basin have been described by the writer and J. D. Sears,[1] and on the north side of the same basin by the writer.[2] In the Green River basin, the lower member consists of light-brown to buff finely laminated shale, ostracod-bearing limestone, oölite, and sandy limestone, together with paper-thin beds of relatively low-grade oil shale, thin and usually well-bedded sandstones, and a conspicuous number of calcareous alga reefs.

The rocks in the corresponding series in the Uinta Basin are in general similar lithologically to those farther north, but have perhaps a larger percentage of sandstone and a smaller number of calcareous alga reefs. This member is only 100 to 300 feet thick in Wyoming, but in the Uinta Basin it attains a thickness, locally at least, of more than 700 feet.

FOSSILS

The fossils associated with the beds of this stage are the following:

Caddis-fly larval cases	Turtles
Ostracods	Gar-pike scales
Calcareous algae	Fish-bone fragments
Mollusks	Dipterous larvae
Crocodiles	

The caddis-fly larval cases represent two genera and species, and occur in considerable numbers at three different horizons and as many localities in the Green River Basin. In each instance the larval cases are included in either an oölitic or algal limestone which carries an abundance of ostracods. One species of insect, in fact, made its larval cases exclusively of ostracod valves.

[1] J. D. Sears and W. H. Bradley, "Relations of the Wasatch and Green River Formations in Northwestern Colorado and Southern Wyoming," *U. S. Geological Survey Professional Paper 132-F* (1924), pp. 96–100.

[2] W. H. Bradley, "Shore Phases of the Green River Formation in Northern Sweetwater County, Wyoming," *U. S. Geological Survey Professional Paper 140-C*, in preparation.

Since the larvae of these insects live in fairly well-aerated fresh water, their consistent association with the oölitic and algal limestones becomes a significant factor in the interpretation of the entire series of beds in which oölitic and algal limestone is so widespread. The same or closely related species of ostracods which occur so intimately with the trichopterous larvae are also exceedingly abundant throughout the lower member of the Green River formation. The significance of these oölitic and algal limestones as criteria for the recognition of fresh-water deposits is further strengthened by the very common occurrence in them, over wide areas, of fresh-water Mollusca.

Such vertebrate fossils as crocodiles and river turtles have been found only in known shore phases of the Green River formation on the north side of the Green River and Uinta basins, and there very close to known shore lines, so they are of little value in this discussion. They merely assist in the interpretation of the ecologic conditions which attended the deposition of this early stage of the Green River formation.

It has been the writer's experience, however, that the bony scales of *Lepisosteus* and fragments of rib bones, rays, and vertebrae of other fish are of very common occurrence throughout most of the Tipton shale member and Tipton tongue of the Green River formation in the Green River Basin, and that entire skeletons are indeed rare. The fragmentary bones are of little if any value except to show that the lake supported an active fauna, but the general distribution of the fresh-water genus *Lepisosteus* appears to be more significant. *Lepisosteus* scales are also found in the lower member of the Green River formation in the Uinta Basin, but how general their distribution there may be is not known to the writer.

In the Uinta Basin the upper part of the lower member of the formation contains at one locality innumerable quantities of the minute larvae of fungus-gnats (*Mycetophilidae*). According to Williston,[1] these larvae live in wet, decaying organic matter, particularly fungi. Their presence in such numbers suggests the abundance of decaying vegetation on mud flats. The shales that contain them are low-grade oil shales.

[1] S. W. Williston, *Manual of North American Diptera* (1896), p. 15.

THE MIDDLE OR OIL-SHALE MEMBER OF THE GREEN RIVER FORMATION

STATEMENT OF THE PROBLEM

The middle member of the Green River formation in both the Uinta and Green River basins contains the beds of oil shale and is, therefore, the object of greatest interest.

Perhaps all purposes will be best served if the writer presents for the criticism and discussion of the reader his opinions regarding the origin of the oil shale and the evidence upon which these opinions are based. The writer's ideas are but tentative, as, indeed, they must be at this stage in the investigation of so involved a subject. The additional data here presented serve in a measure to indicate the growing complexity of the problem, but the preliminary conclusions may be simply expressed thus: The organic matter, which upon distillation yields shale oil, was derived almost wholly from plankton organisms, largely microscopic plants, which lived in the surface waters of shallow, fresh or perhaps mildly saline lakes. These lakes, however, were subjected to periodic reductions in volume which not only greatly concentrated the plankton already present, but also stimulated a vastly greater production of it by reason of the stagnation of the water and a corresponding rise in temperature. Since the microscopic surface-dwelling animals, the zoöplankton, depend directly upon the microflora and the same sources of food as the microflora, it is to be expected that the animals were also present in great abundance, but to what extent they contributed to the origin of the oil shales is as yet a matter for conjecture. The periodic evaporation of these lakes resulted sometimes in actual dryness and brecciation of shale, while at other times it resülted merely in reducing the putrefying organic mass to a syrupy consistency. It is uncertain as yet to what degree the dissolved inorganic salts in these lakes were concentrated by evaporation.

In substance this is the writer's present conception. Below are presented some of the observations which are responsible for this opinion.

METHOD OF ATTACK

In order to make an intelligent interpretation of fossil lake beds, it seemed entirely logical to acquire first some knowledge of the

kinds of deposits that are now accumulating in inland lakes. An examination of the literature revealed the fact that almost nothing had been done in this country with such a study of lacustrine deposits. In Europe, however, several investigators had studied and classified in considerable detail the kinds of organic ooze that characterize the various kinds of lakes. The motive for such studies was either for the advancement of pure biologic science or to obtain information for use in the fisheries industry.

The bearing of the results of such investigations on the problem in hand can be shown most concisely in tabular form. (See Table I.) In the first and third columns the characteristic features of the two most common types of lake, as determined by their sediments, are summarized from Naumann.[1] In the middle column the writer has summarized the characteristics of the ancient Green River lakes for comparison.

A very striking parallelism between the Green River lakes and the sapropel lake type of Naumann is at once apparent. The characterizing features of the Green River lakes, however, are doubtless not so self-evident and therefore demand some further discussion and eduction of observational data. In spite of the fact that the method savors strongly of painfully prolix sermons where the sixthlies and seventhlies are dwelt upon at length, it will probably be most lucid in this instance to consider the points numerically as they appear in the above table.

1. *Probable large plankton production.*—There are three lines of evidence which indicate that the dominant part of the organic matter in the ancient Green River lakes resulted from a luxuriant growth of surface-living microscopic plants. In the first place, the distribution of the organic matter is such as to suggest that it was produced very close to the place in which it is now found. By far the greatest amount occurs quite uniformly distributed in the central parts of both the Uinta and Green River basins and decreases in all directions toward the shores until in the actual shore phases oil shale is entirely absent or is represented by only a few thin beds of low-grade oil shale.

[1] Einar Naumann, "Die Bodenablagerungen des Süswassers," *Archiv für Hydrobiologie und Planktonkunde*, Vol. 13 (1921–22), pp. 100–186.

TABLE I

(After Naumann) Sapropel or Faulschlamm Lake Type	Ancient Green River Lakes	(After Naumann) Torfschlamm or Humus Lake Type
1. Large plankton production.	Probable large plankton production.	Small plankton production.
2. Carbonaceous matter largely in the form of the humified remains of higher plants and colloidal humus. Insignificant here.	Remains of higher plants insignificant. Apparently humus content insignificant also.	Both factors essential here.
3. Peat bogs not present around shore or at most of small dimensions.	Fossil peat bogs inconspicuous in the marginal deposits and at equivalent horizons in the Wasatch.	Contiguous peat bogs essential.
4. Waters lime-rich.	Waters lime-rich.	Waters lime-poor.
5. Wind-blown pollen and spores present. Dependent on adjacent forest growth.	Present. Dependent upon adjacent forest growth.	Present. Dependent upon adjacent forest growth.
6. Abundant nektonic and benthonic fauna.	Abundant nektonic fauna. Probable abundant benthonic fauna.	Scanty fauna of both kinds.
7. Coprolitic structure usually wanting except on the surface of the ooze.	Coprolitic structure wanting.	Coprolitic structure usually pronounced.
8. Bacterial flora very rich.	Few fossil bacteria. Abundant evidence of bacterial decomposition.	Bacterial flora not well developed.
9. A summer maximum temperature high enough to support water bloom.	The larger land plants, the insects, and the animals suggest sufficiently high temperature for large plankton development.	Any temperature, but this type is more characteristic of the cooler climates.
10. Deposit relatively rich in fatty and waxy matter. High in C and H, low in O.	Deposit relatively rich in fatty and waxy matter. High C and H, low O.	Deposit relatively poor in fats and waxes. High in O, low in C and H.
11. Yields largely gaseous and oily distillates.	Yields petroleum-like distillates and gases.	Yields large amount of H_2O and tarry residues on distillation.

The microscopic study of the oil shales tends to support this hypothesis of an autochthonous origin for the oil-forming material. Although much of the organic matter in the oil shale is nearly or entirely structureless, there are imbedded in it a great many organisms whose original form, and in rare cases even internal structures, are remarkably preserved. Of these identifiable organic remains, pelagic algae, belonging mostly to the Cyanophyceae and Chlorophyceae, and filamentous fungi are the most numerous forms encountered. A survey of 92 photomicrographs of oil shale made by C. A. Davis, showing 112 distinct organisms, and 65 camera lucida drawings by the writer, figuring as many organisms or groups of organisms, reveals the following figures:

Phytoplankton	42
Spores of fungi	30
Filaments of fungi	29
Pollen and spores from higher land plants	28
Uncertain organisms, largely cellular filaments	27
Benthonic algae	23
Parts of higher plants	5
Insects and insect fragments	3

Most of the plankton flora in this list show a more or less distinct radial symmetry.

The fungi are all very minute and simple in form. They were probably saprophytic in habit. The writer found similar fungi living in the decaying organic ooze which he collected from Goose Lake in Oregon. However, this by no means disproves that the fungi, particularly the spores, in the oil shale were carried in from some outside source.

The pollen and spores of higher land plants were evidently transported there by wind and water currents and, as would be expected under such circumstances, their distribution in the oil shale is erratic. In some shales they form a conspicuous part of the organic matter and, as they are rich in waxy material, contribute rather notably to the oil yield of that shale upon distillation. Other shales, on the contrary, contain few if any pollens or spores of land plants, and yet may produce equally large quantities of oil upon distillation.

The uncertain organisms are either cellular filaments or broad,

flat, and apparently unicellular thalli which may have had a definite attachment to the substratum or may perhaps have been free living.

A more or less definite organ of attachment distinguishes the bottom-dwelling plants.

The parts of higher plants, except for the pollens and spores, are conspicuous by reason of their infrequence in the oil shale. C. A. Davis[1] records two fern annuli and one group of bark cells. To this list the writer can add but two more in the form of a sclerenchymatous fiber and a portion of a spiral tracheide. It is perhaps significant that the bark cells, sclerenchyma fibers, and spirally thickened walls of tracheides are quite strongly lignified or suberized and hence resistant to decay. The walls of the tracheide had entirely disappeared, leaving only the spiral thickening. The paucity of the remains of higher land plants constitutes the third reason for believing that the dominant part of the organic matter of the oil shale was produced within the lake.

Unique among the microfossils of the Green River oil shale is a finely preserved water mite photographed by Davis. Its presence is quite suggestive, since the hydrachnids are almost without exception confined to bodies of fresh water rich in plant and animal life. In addition to this complete insect, Davis records a fragment of an arthropod leg, and the writer has found still another.

It is the purpose of the writer to treat more at length the micropaleontology of the Green River formation and its bearing on the origin and nature of the oil shale in a paper for publication by the Geological Survey.

2. *Remains of higher plants insignificant.*—As far as the oil shale itself is concerned, this is apparently true. The macroflora, represented by so many finely preserved leaves, is confined, so far as the writer is aware, to the upper and basal members of the Green River formation, which are largely devoid of oil shale. These leaves may have been transported considerable distances by wind and water currents. Precipitated humic acid, which is derived from higher land or aquatic plants, is apparently present in very small amounts in the oil shale, or for that matter at any horizon in the Green River formation.

[1] Unpublished photomicrographs.

3. *Marginal peat bogs absent.*—In order that the organic matter of the oil shale should have been derived dominantly from extraneous sources, it seems probable that marginal swamps and peat bogs would have to be postulated. As far as the writer's field observations go, carbonaceous shale (not oil shale) and coal, the expression of such swamps, are notably rare in the marginal phases of the Green River formation, or even at the stratigraphically equivalent horizons in the closely related Wasatch formation, and where they do occur, as in the southeast corner of the Green River Basin, the oil shale is negligible.

4. *Waters lime-rich.*—The abundance of limestone throughout the formation bears evidence to this statement. Moreover, much of the finely divided mineral matter in the oil shale is calcite. Calcareous alga reefs and oölitic limestones are also in agreement with these other data.

5. *Wind-blown pollens and spores.*—These were discussed above with the micropaleontology, and they require no further comment here.

6. *Abundant nektonic and benthonic fauna.*—Numerous beds of considerable lateral extent composed largely, and in some instances entirely, of ostracods attest this statement. In further support may be added the widespread occurrence of fragmentary fish bones and local abundance of complete skeletons. It is true that these forms are found chiefly in the marginal phases of the three members. In more direct association with the oil shale, however, the writer found at several localities in the Uinta Basin groups of the bony scales and partial skeletons of *Lepisosteus*, and Cope[1] specifically mentions at least one genus, *Erismatopterus*, as occurring in bituminous shale. Both of these genera are distinctly fresh-water inhabitants. The benthonic forms are represented locally by Mollusca. In the absence of positive evidence in the form of fossils, it may or may not be an unwarranted assumption to postulate from these data the existence in the Green River lakes of the common associates of such a lacustrine fauna, namely, Protozoa, Nematoda, Crustacea, etc.

7. *Absence of coprolitic structures.*—An apparent paradox arises

[1] E. D. Cope, *U. S. Geological and Geographical Survey Terr. Ann. Rept.*, Vol. 4 (1870), p. 428.

here, since the deposits formed in the lakes containing abundant food and an active fauna show no coprolitic structure, whereas those deposits which accumulate in the humus-rich, food-poor, and therefore also fauna-poor lakes show a well-defined coprolitic structure. Naumann[1] explains this from the observed facts that in the former (the sapropels or Faulschlamms) the excrement balls fall apart very quickly, due to the activity of a rich bacterial flora and the activity of other small ooze-dwelling organisms, while in the latter (the Torfschlamms or humic oozes) what excrement there is very commonly shows a remarkable resistance to disintegration, due to an absorption phenomenon with humus stuff and iron salts.

8. *Rich bacterial flora.*—C. A. Davis photographed several areas of trichobacteria in the oil shale, and the writer has since found them to be not uncommon in many of the thin sections of higher-grade oil shales. These exceedingly small forms are best observed in microtome cut sections from which all the mineral matter has been removed. Sections so cut have the advantage of freedom from distracting light diffusion through minute mineral particles at high magnifications. Besides actual bacteria, the presence of such large quantities of structureless, or nearly structureless, organic matter indicates bacterial reduction on an extensive scale. Microscopic plants have been observed by the writer[2] in other oil shales which exhibit all transitions between the nearly perfect thalli of a planktonic alga and mere yellow blebs with only the outline left to betray the original organism. The cessation of bacterial activity in the original organic ooze presents a more acute problem than accounting for the presence of bacteria. These organisms always give rise to the formation of organic acids which, in the absence of sufficient water, may become so concentrated as to be effective toxins to the bacteria themselves and thus produce a state of asepticity. Potonie[3] has suggested a physical phenomenon such as excessive compacting by superincumbent layers. The presence of brecciated structures, mud

[1] *Op. cit.*, p. 118.

[2] W. H. Bradley, "An Oil Shale and Its Microörganisms from the Fuson Formation of Wyoming," *Amer. Jour. Sci.*, Vol. 8 (1924), pp. 228–34.

[3] H. Potonie, "Die rezenten Kaustobiolithe und ihre Lagerstatten," *K. preuss geol. Landesanstalt*, Vol. 1 (1908), p. 16.

cracks, and mud curls in many of the high-grade oil shales of the Uinta Basin leads the writer to believe that periodic, very decided reductions in volume of the water occurred in the basins where the mother-substance of oil shale accumulated. Such reductions in the quantity of water available might be an effective curb to the putrefactive tendency, or it may even be that the increasing concentration of mineral salts in such evaporating basins may have resulted in the sterility of the mass. Calcite-filled cavities up to two millimeters in length in the oil shale lend some credence to this theory. A satisfactory solution of this phase of the problem, however, requires more extended investigation.

This biochemical stage through which the original organisms must have passed may be a critical point in determining the difference between an oil shale and an organic shale which becomes a source rock for petroleum.

9. *Relatively high summer temperature.*—Naumann[1] in discussing the optimum conditions for the accumulation of sapropel states that a minimum summer temperature of 16° C. is necessary to the production of a luxuriant plankton flora and is nearly as important as the presence in the water of abundant nutrient matter and dissolved lime salts. The subtropical aspect of the lower-zone flora of Knowlton[2] and of the insects as discussed by Cockerell in Winchester's bulletin[3] are suggestive, if not entirely convincing, of a summer temperature high enough for abundant plankton production.

10. *Oil shale relatively rich in carbon and hydrogen.*—Ultimate analyses of oil shales show that they are considerably higher in hydrogen and carbon relative to oxygen than are even cannel coals which yield much oil upon distillation.

11. *Yields petroleum-like distillates.*—The fact that this statement is true accounts for the present interest in and study of the Green River formation.

[1] *Op. cit.*, pp. 149–56.

[2] F. H. Knowlton, "Revision of the Flora of the Green River Formation with Description of New Species," *U. S. Geological Survey Professional Paper 132-F* (1923), pp. 145–48.

[3] D. E. Winchester, "The Oil Shale of the Rocky Mountain Region," *U. S. Geological Survey Bull. 729* (1923), p. 22.

UPPER MEMBER OF GREEN RIVER FORMATION

LITHOLOGY

The upper member is represented in the Green River Basin by several hundred feet of brown sandy and limy shale, gray to brown sandstone, and a few oölitic or pisolitic limestones and calcareous alga reefs. At Green River, Wyoming, this member includes the so-called "plant beds," from which have come many species of the known Green River flora.

In the Uinta Basin, the upper member of the Green River formation is less well defined, but for the present purposes it might be regarded as including the more or less barren shales above the oil-shale member and an indefinite thickness of coarse-grained cross-bedded sandstone above.

CLIMATIC CHANGE

The rocks of the upper member of the Green River formation in the Uinta Basin furnish evidence of an altogether unique but probably local aspect of Eocene climate, namely, distinct aridity. Through several hundred feet of the barren shale the impressions of salt crystals are exceedingly common. They cover the bedding-planes of the shales or occur as large knotty aggregates of crystals with a generally radial structure. These larger groups of crystals, which attain a maximum diameter of more than a foot, evidently grew in place when the mud was still plastic, for the bedding is much distorted to accommodate them. In the canyon of Evacuation Creek, just a few miles north of Watson, Utah, the cavities from which these salt nodules have been dissolved are conspicuously abundant.

Dr. W. F. Foshag, of the United States National Museum, examined the molds of these crystals and took casts of them for measurement. It was impossible to obtain wholly satisfactory casts, because of the intricate intergrowth of the original crystals, but he believes they are almost certainly the molds of glauberite crystals, $Na_2Ca(SO_4)_2$, and as such are satisfactory indicators of strongly saline lakes or playas and at least of periodic drastic droughts if not of continued aridity. In addition to these molds, which either stud the bedding-planes or are isolated in the shale,

the writer found shales with a finely developed system of deep mud cracks, the vertical fissures of which are completely filled with calcite casts of salt crystals.

Some interesting but as yet unstudied occurrences of very rich oil shale in immediate association with the large salt nodules in the Uinta Basin were observed by the writer in the past summer. In one of these occurrences the bedding of the oil shale is sharply curved to conform to the shape of a large salt nodule. It is perhaps germane to note here that the locality near Watson, Utah, where these salt molds are most abundant is also the locality of the remarkable gilsonite veins. Mr. Thomas J. Davis,[1] of Watson, Utah, observed a very viscous asphalt-like substance exuding from a bed of oil shale in this same vicinity. It is as yet unknown what bearing these observations may have on the problem of the origin of petroleum, especially as regards the accepted but thus far unproved hypothesis that salt of some kind is a prerequisite to the origin of petroleum. It is a problem well worthy of protracted study.

If it is true that at this stage of Green River history the lakes were periodically reduced to very low levels and even to dryness, it is less difficult to account for the abundance of winged insects found in this member. In his studies of the saline lakes of the Mojave Desert, Dr. Foshag[2] observed that great swarms of insects, particularly Diptera, in both adult and larval stages, frequented the shores and mud flats of such playas. The present writer observed the same to hold true around the shores of Goose, Abert, and Warner lakes in southern Oregon. The decaying vegetable débris at the water's edge is apparently a favorable habitat for such insect larvae. Adult insects stuck on the wet mud are soon covered by dust or, if the wind is in the right direction, the water is frequently raised enough so that it spreads several feet over the almost flat mud shores and covers the insects with fine silt and mud. The slope of the shores and bottoms of these shallow lakes is so gentle that even in violent wind storms the water near the strand line is barely more than rippled. At such times of temporary expanse of water, small fish are frequently stranded and subsequently buried in the same manner as the insects.

[1] Personal communication.

[2] Personal communication.

Somewhat more problematical, as pointed out by Professor Henderson, is the widespread occurrence of vast numbers of bot-fly larvae, all the modern genera of which are known only as parasites of mammals. In the absence of any suggestion that mammals were abundant enough to account for such legions of these larvae and the absence of a single mammalian bone from the shales of this member, the writer is tempted to offer a radically different explanation, namely, that these Eocene Oestridae larvae were saprophytic in habit and acquired their parasitic habit in later geologic time. Many instances of such an acquisition of parasitic habit are known, and after all, an existence in the intestinal tract of a herbivorous mammal does not involve a very profound change from a life in wet, decaying vegetable débris. So far as the writer is aware, none of the fossil Oestridae of the Green River have been referred to the genus *Gastrophilus*, the larvae of which dwell in the stomach and intestines of the host. Such a step might appear simple of explanation, but the living representatives of *Hypoderma* and *Cephenomyia*, to which genera the bot flies of the Green River formation are referred, are known to live either in tumors under the skin or in the nasal sinuses and throats of certain mammals. This step perhaps offers a greater obstacle to accepting the writer's suggested hypothesis, and yet the fact remains that the fossil larvae representing these two genera are associated in the Green River formation with such dipterous larvae as the Syrphidae and Mycetophilidae, both of which families pass their larval stages in wet, decaying vegetable matter.

In the upper, or Morrow Creek, member of the Green River formation in the Green River Basin, there is as yet little evidence of such pronounced aridity. At one place only were calcite-filled salt molds found. It may perhaps be that local highlands produced different ecologic conditions in the two basins, or it may well be that the evidence for aridity has not yet been revealed in the Green River Basin.

RECAPITULATION

The Green River formation as a whole is admittedly lacustrine, but instead of representing the deposits of two large, broad, and probably deep lakes, it represents the deposits of many different kinds of lakes produced in consequence of a long series of changing

conditions. Its geologic history is complicated by progressive climatic and, consequently, ecologic changes, upon which were probably also superposed periodic or cyclic phases of shorter duration.

Although it is hazardous to attempt to generalize at this stage in the solution of the problem, it appears that there is a discernible trend in the history; with this adumbrated vision of trend in mind, the writer recapitulates the geologic history of the Green River formation.

The first deposits of the Green River formation accumulated in two large but relatively shallow fresh-water lakes under a climate that may be described as prevailingly warm and moist but yet of such a seasonal nature that it alternately favored and inhibited the growth of woody plants.

Following this phase was a somewhat longer stage in the history of the formation, in which the seasonal aspect of the climate became more pronounced, but the relatively high temperatures persisted. An alternation of moist and dry periods with increasing emphasis on the periods of drought appears to have characterized this stage. Under this climate the depositional basins alternately flooded and evaporated either partially or completely. It was in these shallow lakes, which may be pictured as broad sheets of water at the end of the rainy season and as a large number of disconnected ponds of various sizes at the close of the dry season, that large volumes of microscopic plants and perhaps also animals accumulated, to be subsequently covered by other deposits and lithified into oil shale. The water of these remnant ponds probably became more or less highly concentrated in mineral salts, depending upon the degree of reduction in volume.

As a closing phase in the history of the Green River formation, the climate became prevailingly dry with only brief moist periods. Under this climate the lakes became playa-like and the concentration in mineral salts became so high that salts crystallized out in the wet muds. Moisture, however, was certainly available in the country surrounding the playa basins, since the Green River flora apparently flourished at this time. It may well be that the aridity was but a local phenomenon such as obtains in the Great Valley of California today, and that similarly the mountain slopes were well watered.

THE SARATOGA OIL FIELD, HARDIN COUNTY, TEXAS[1]

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ABSTRACT

Although the salt has not been drilled into, the presence of a typical cap-rock mass of anhydrite and gypsum capped by "lime" rock indicates that Saratoga is a salt dome. The cap rock is elliptical in plan with its major axis about 1½ miles in length and northeast-southwest in strike. The beds penetrated in drilling range in age from Jackson (Eocene) to Pleistocene. The oil is found on a series of lensing supercap sands. Oil was first produced thirty years ago from a shallow well and used for medicinal purposes. The real discovery of the oil field followed shortly after the discovery of Spindletop. The production reached a maximum of 3,000,000 barrels in 1903, and on account of the successive discoveries of new "sands" has fallen off moderately slowly. The crude oil is an 18° Baumé oil with a high content of lubricant stock but also with a rather high content of sulphur. Dates are given in regard to production methods and costs.

D. C. B.

INTRODUCTION

Location.—The Saratoga oil field is located in Hardin County, Texas, about 50 miles northwest of Beaumont. It is reached by a branch of the Gulf, Colorado & Santa Fe Railroad extending 10 miles south from Bragg, a station located on the main line between Beaumont and Somerville. Saratoga is about 13 miles slightly west of north of the Sour Lake field, and about 7 miles northeast of the Batson field.

History.—Attention was first attracted to Saratoga as a possible oil field because of surface indications similar to those at Sour Lake. The sulphureted and sour waters at Saratoga were considered very beneficial to the health in the early days, and people came in considerable numbers in the summer time to drink them. Gas seepages had been noted here for years, as had also seepages of oil. Fenneman[2] states that there were at Saratoga "certain spots in which the soil is impregnated with asphaltic substance."

[1] Published by permission of E. T. Dumble, consulting geologist, Southern Pacific Co., Houston, Tex.

[2] N. M. Fenneman, *U. S. Geol. Survey Bull. 282*, p. 58.

The first well at Saratoga of which we have record was located just southwest of the center of the J. F. Cotton tract. It is interesting to note that this well was about in the center of the present productive pool. It was drilled with very primitive tools but actually produced a small amount of oil by bailing, the oil being used for medicinal purposes. In 1896 Savage Brothers became interested in Saratoga and drilled a well to a depth of 250 feet near this first well, obtaining a small amount of water and oil. Later, W. P. Conroy started a well about ½ mile to the south, but the tools became stuck at 120 feet and he was forced to abandon the test. Savage Brothers drilled several shallow wells with cable tools in the southwestern part of the J. F. Cotton tract between 1896 and 1900, but without any pronounced success.

After the bringing in of the Spindletop pool in 1901, interest was renewed in Saratoga and considerable drilling was done. The Saratoga Oil and Pipe Line Company completed their No. 1 Hooks (Rio Bravo Oil Company No. 200), at a depth of 995 feet, with an estimated production of 500 barrels. This well was located near the middle of the north line of the J. F. Cotton 157-acre tract. Their No. 2 Hooks (Rio Bravo Oil Company No. 201), was drilled to 1,600 feet, and brought in as a producer at a depth of 700 feet. The well was located near the site of the Savage Brothers' drilling. The holdings of the Saratoga Oil and Pipe Line Company, comprising all the land on the B.B.B. & C. survey No. 132, R. Teel, J. F. Cotton, and 93.69 acres of the C. F. S. Jordit survey, were taken over in 1903 by the Rio Bravo Oil Company.

During 1903 intensive exploitation took place in the vicinity of the northwest and southwest corners of the J. F. Cotton tract. During this year the field is credited with a production of 150,000 barrels of oil. The principal operators in the field at this time were Producers Oil Company (The Texas Company), J. M. Guffey Petroleum Company (Gulf Production Company), Rio Bravo Oil Com-Company (Southern Pacific Company), and the Santa Fe Railway Company. Up to August, 1904, some $200,000 had been spent in drilling and the field production had seldom been over 1,500 barrels per day. At about that time, a rich sand was discovered at a depth

of about 1,500 feet in a well drilled by the J. M. Guffey Petroleum Company on the Greer tract in the northwest corner of the C. F. S. Jordit survey. The Producers Oil Company brought in their No. 4 for 10,000 barrels per day, and the Austin Oil Company brought in their No. 1 Moore for 12,000 barrels per day. In May, 1905, the Rio Bravo Oil Company brought in their No. 222 Cotton for an initial production of 3,700 barrels per day. As a consequence of the development following upon the bringing in of these large wells, the production for 1905 amounted to almost 3,000,000 barrels, the largest production for any year in the history of the field. For a short time in the early part of 1905 the daily production at Saratoga amounted to 20,000 barrels per day. In February, 1905, salt water began to show in the large wells and the daily production slumped to less than 10,000 barrels per day. With the exception of the large wells completed in 1904–5 it might be said that the average completion at Saratoga is a small well, seldom good for more than 400 barrels per day.

The production at Saratoga gradually fell off until in 1911 it was less than 1,000,000 barrels. In 1912 a good sand was developed at about 1,200 feet in the northeast part of the C. F. S. Jordit No. 1 survey, and an active drilling campaign ensued. As a consequence, the production for 1912 rose to 1,100,000 barrels. The production of the field gradually declined from 1912 to 1917, during the last year of which period but 683,000 barrels were produced. In 1918 new production was discovered in the extreme northwest corner of the Nancy Fuller survey and southwest corner of the R. Teel tract. This production, which came from around 1,900 feet in depth, raised the 1918 production to 790,000 barrels. In the latter part of 1920 and early part of 1921, production was developed by the Sun Company, Gulf Production Company, and Weldon Oil Company from a shallow sand (600–800 ft.) in the Mary E. Hopkins No. 1 survey just west of the northwest corner of the J. F. Cotton tract. This caused a drilling boom which increased the 1921 production to 936,000 barrels. The various booms at Saratoga can be noted very clearly on the yearly production curve shown in Figure 1.

In December, 1923, drilling activity at Saratoga was at its lowest

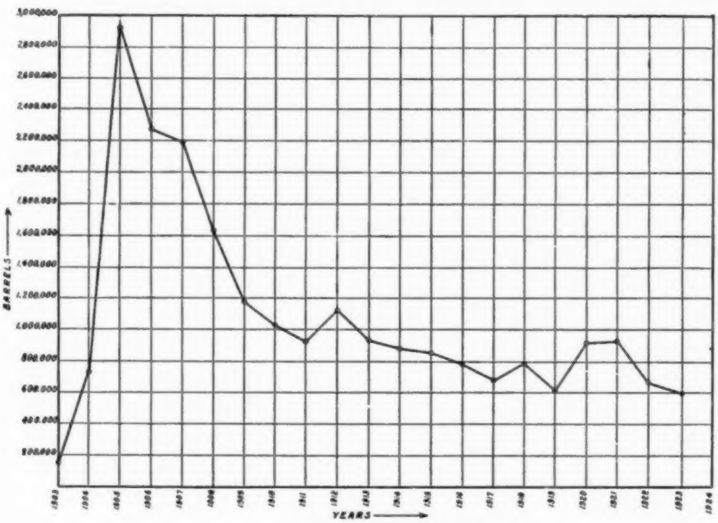


FIG. 1.—Yearly production, Saratoga field

ebb; only two rigs were running in the field; and the daily production had fallen off to 1,500 barrels per day divided as follows:

	Barrels
Rio Bravo Oil Company	600
Sun Company	320
Gulf Production Company	100
Paggi Brothers	170
Weldon Oil Company	140
Regna Oil Company	70
Miscellaneous	100
Total	1,500

The production for 1923, 603,000 barrels, was the lowest in the history of the field.

GEOLOGY

The Saratoga field is on the outcrop of the Columbia sands, as mapped by Kennedy. As shown by the accompanying map (Fig. 2), the total amount of relief within the field is about 40 feet. The surface is considerably dissected by drainage from Pine Island Bayou to

the south and Black Creek to the north. As topographic relief of 40 feet is not uncommon in the area of Columbia sand outcrop, it is doubted if the topography has much relation to the subsurface dome. It is also to be noted that the highest part of the field, topographically, is about 3,000 feet slightly north of east of the highest elevation of the dome.

The soil in the Saratoga field is very sandy, and the surface was heavily forested at the time oil was first discovered. The timber has been removed, for the most part, as the drilling has proceeded.

Underlying the Columbia sands which outcrop at Saratoga are the Lafayette sands and gravels. For the most part these are fresh-water sands, and boiler feed water is obtained from them down to 500 feet. As the Beaumont clays are not found at Saratoga, the ratio of sand to clays penetrated is much higher than in almost any other field on the Gulf Coast.

The geological formations penetrated at Saratoga are as follows:

	Thickness in Feet
PLEISTOCENE	
Columbia sands. Gray sand and gray and brown mottled sandy clays	100– 150
PLIOCENE?	
Lafayette. Sands and gravels. Coarse "rice sands" and fine gravel with some clayey layers. Formation carries good grade of fresh water where underlying salt water has not been allowed access to it by drilling. Locally cemented into hard sandstone	400–1,300
MIOCENE	
Fleming equivalent. Blue gumbo and shales with sand and shale development locally. Sands are gray colored and medium fine grained. Fossil sea shells and Foraminifera found in this formation classify it as Miocene in age and either the time equivalent of the Fleming formation or slightly older	700–1,200
OLIGOCENE	
Series of green-gray and lavender shales and gumbos and sandy shales in Gulf Production Company No. 2 Teel and Rio Bravo Oil Company B-83 have been classified on paleontologic evidence as Oligocene. Also black shales have been encountered in a few instances in Saratoga wells. Such shales from 1,910 feet in Rio Bravo Oil Company No. B-25 have been classified as Oligocene	200– 700

EOCENE

Jackson sandstones. Jackson fossils are reported as having been found in cores taken from Rio Bravo Oil Company well No. 218.* The records giving the depth at which they were found and the name of the forms have been lost and we are unable to give complete details.

* *Trans. A.I.M.E.*, Bull. 104 (1915), p. 1632.

Saratoga is a rather deeply buried dome. The highest point on the cap rock is about 1,500 feet below the surface. Saratoga is a large, rather broad, flat dome with gently dipping sides (Fig. 3). The dome is roughly elliptical in shape with its longer axis extending in a general northeast-southwest direction. At a depth of 2,000 feet, it is $1\frac{1}{2}$ miles across along the longer axis. The dip on the cap rock from the center of the dome outward, as shown by the cross-sections, is flat—as nearly as can be measured about 10° to the northeast and about 9° to the southwest. With the possible exception of occurrence of Jackson fossils rather high in one well, the drilling to date has failed to give any evidence of faulting on the sides of the dome, but it is possible that such faulting does exist to the northwest or to the extreme southeast. The logs of the few deep wells which have been drilled on the edge of the dome show conclusively that the dip of the cap rock becomes much steeper after the 2,700-foot contour is crossed. This is well shown in the cross-sections (Fig. 4).

The Saratoga dome is very peculiar in some respects. In only one well, the Sun Oil Company No. 134 McShane, in the extreme northeastern part of the field, has rock salt been logged. Mr. R. W. Pack,[1] manager of the Sun Company, states that although the formations were very salty, it is not definitely known that rock salt was encountered as no cores were taken.

Well No. 259 Jordit, of the Rio Bravo Oil Company, logs limestone and rock from 1,555 to 1,758 feet, a total thickness of over 200 feet. Professor W. F. Cummins has informed the writer that the cuttings from this well consisted principally of anhydrite and selenite. In the contouring of the dome, the top of the thin limestone cap overlying the anhydrite is taken as the top of the dome. This surface is irregular and in some instances might take in sandstone

[1] Personal communication.

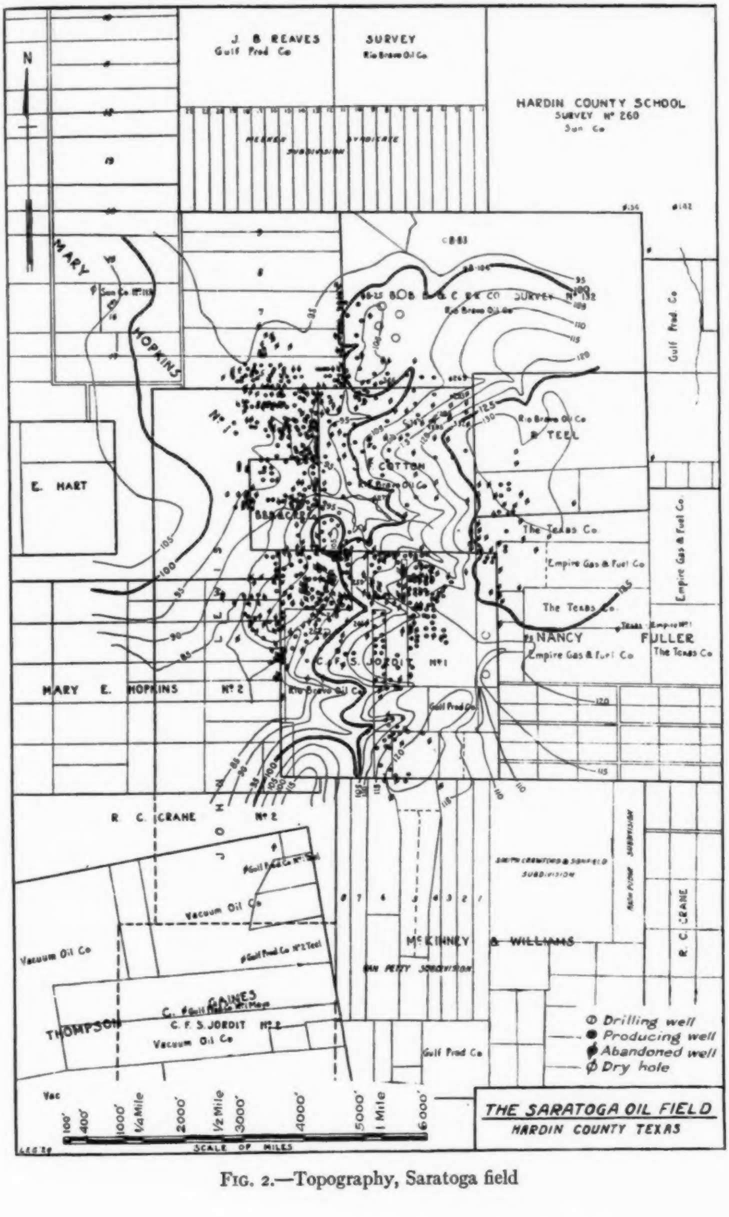


FIG. 2.—Topography, Saratoga field

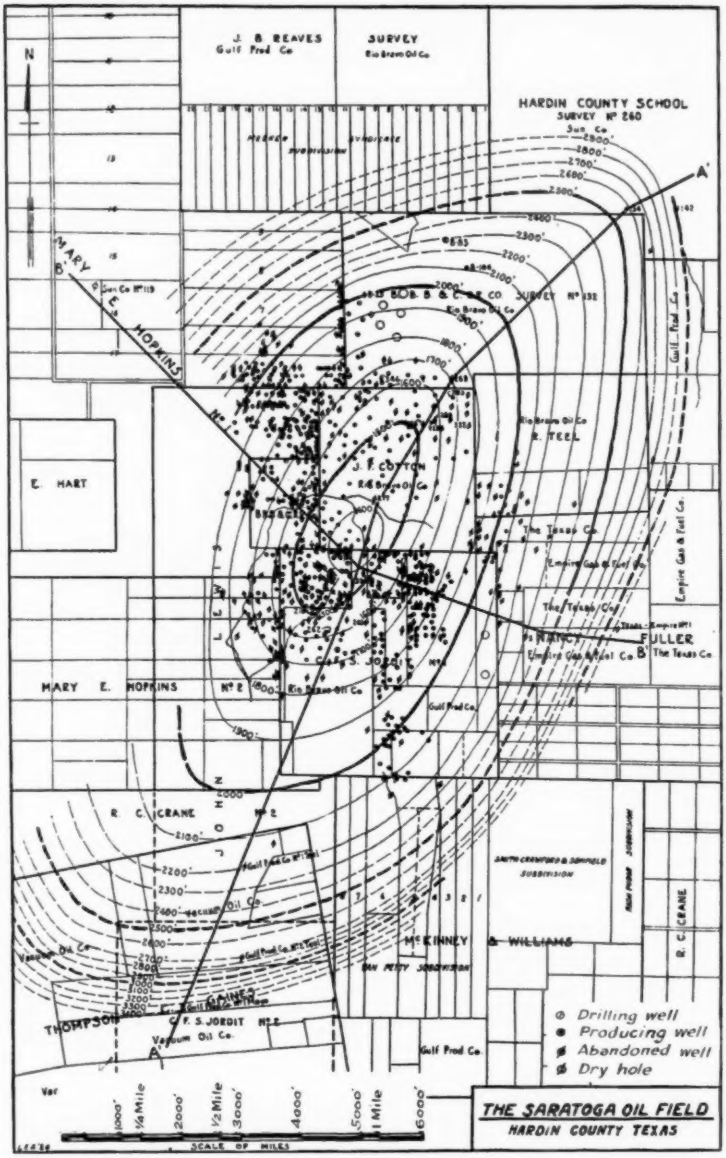
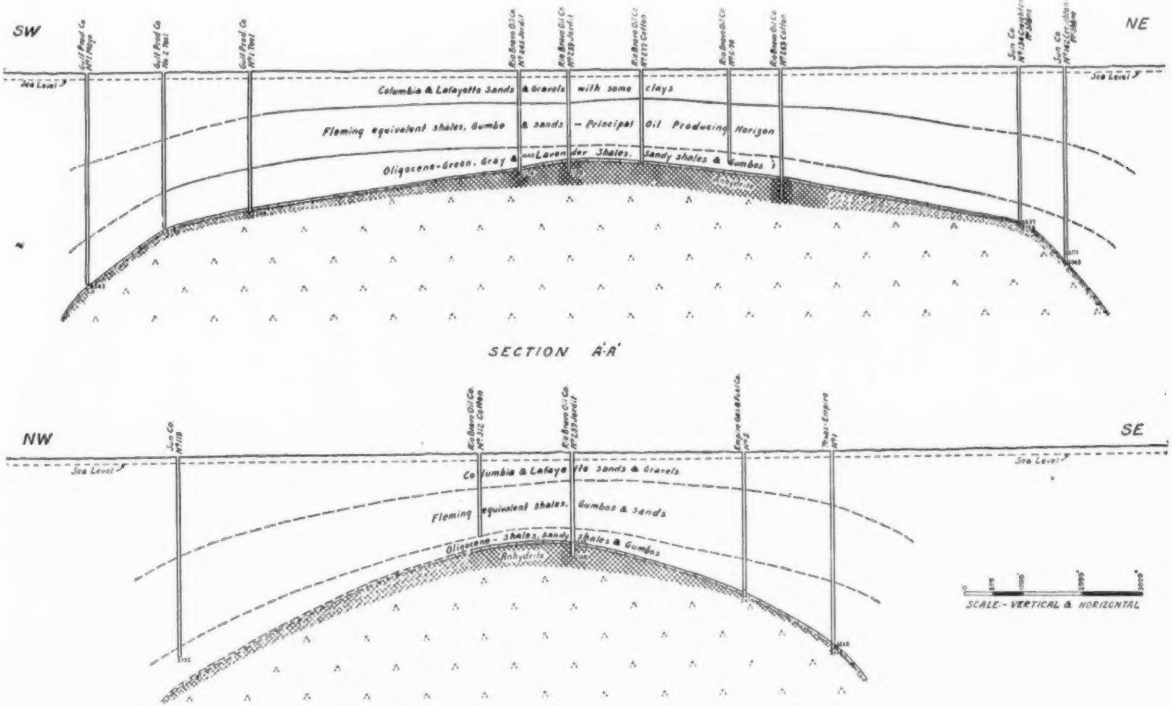


FIG. 3.—Contours on cap rock, Saratoga field. Contours based on elevation below sea-level.



SECTION B-B'

FIG. 4.—Cross-sections of Saratoga salt dome

layers which have become cemented with lime. There is evidence that the limestone cap is thicker in the center of the dome than on the edges. Well No. 332 Cotton, of the Rio Bravo Oil Company, had anhydrite from 1,918 to 2,061 feet and very little limestone. Well No. 269 B.B.B. & C., of the Rio Bravo Oil Company, had about 45 feet of limestone (1,870–1,915 ft.), and then penetrated anhydrite for about 300 feet (1,930–2,224 ft.). Although rock salt is not known actually to occur under the limestone and anhydrite, it is assumed to be there. The thickness of limestone and anhydrite overlying the salt is possibly much greater than in the average dome.

The Columbia-Lafayette sands and gravels covering and surrounding this dome are supposed to lap up on the edge of it and to have a pronounced thickening from the center of the dome outward. The Fleming beds are about 700 feet thick in the center of the field but appear to thicken to about 1,200 feet on the edges. The Oligocene beds thicken from about 200 feet at the center to about 700 feet on the edges.

A considerable fauna of macroscopic fossils has been obtained from certain of the wells drilled at Saratoga. The Miocene has a fairly good invertebrate fauna in the northern part of the field, and Miocene vertebrate remains have been recovered from the southern part of the the field. The Miocene formations penetrated by the drill have yielded a fairly good foraminiferal fauna. The Oligocene has yielded a good foraminiferal fauna but few macroscopic forms. Species found in the various wells are as follows:

FOSSILS FROM WELL NO. 346 B.B.B. & C—RIO BRAVO OIL COMPANY

From a depth of 922–1,000 feet
Divaricella? chipolano, Chipola
Corbula radiatula, Oak Grove
Lucina crenulata, Oak Grove
Arca, close to an Oak Grove species
Cancellaria, quite close but not identical to an Oak Grove species
Nassa? sp.
Terebra sp.
Actaeon sp.
Natica cf. *canrena*
Terebra cf. *dislocata*
Turritella subgrundifera, Chipola

From a depth of 1,040–80 feet
- *Corbula* n. sp., not Galveston well species or Oak Grove
- Fragments of *Chione,* possibly *C. glyptocyna* from Oak Grove
- Fragments of *Arca, Strigillia, Divaricella,* and *Phacoides*
- *Chama,* may be Oak Grove species
- *Turritella* fragment cf. *T. subgrundifera,* Oak Grove
- *Phacoides* cf. *sphaeriolus* Dall, Chipola

FOSSILS FROM WELL NO. 293 COTTON—RIO BRAVO OIL COMPANY

From a depth of 1,140–59 feet
- *Astarte* sp.
- *Turritella* sp.
- *Cardium* sp.
- *Divaricella,* 2 sp.
- *Chione* fragment

From the list it appears that these beds are of Lower Miocene age.

- *Strigillia* sp.
- *Corbula* cf. *swiftiana*
- *Lucina,* close to *L. crenulata*
- *Donax* sp.
- *Cerithium?* sp.
- *Solarium?* sp.
- *Chione,* worn sp. cf. *C. glyptocyna,* Oak Grove

This fauna also appears to be equivalent in age to the Oak Grove. Determinations by Mrs. Dorothy K. Palmer, in the Rio Bravo Oil Company laboratory.

VERTEBRATE REMAINS FROM WELL NO. 262 JORDIT—RIO BRAVO OIL COMPANY

Bones obtained between 400 and 600 feet
- Lower molar fragment of protohippine horse probably *Hipparion* or *Protohippus*
- Shaft of femur of *Merycodus*
- Ungual phalanx, compares closely with *Hipparion lenticulare* Cope
- Lumbar vertebrae of horse (?)
- Fragment of turtle shell
- Jaw fragments probably rhinoceros or camel

This material resembles very much the vertebrate remains obtained on the outcrop from the Fleming formation.

FORAMINIFERA FROM WELL B-83 B.B.B. & C.—RIO BRAVO OIL COMPANY

From a depth of 1,898–1,907 feet

Anomalina n. sp. (*taylorensis*)[1]
Pulvinulina n. sp. (*saratogaensis*)[1]
Frondicularia n. sp. (*saratogaensis*)[1]
Vaginulina n. sp. (*saratogaensis*)[1]
Vaginulina n. sp. (near *bradyi*)[1]
Discorbis n. sp. (*saratogaensis*)[1]
Nodosaria n. sp.
Nodosaria cf. *vertebralis*
Globigerina dubia? var.
Textularia globulosa? var.
Pulvinulina n. sp. (*hardini*)[1]
Cristellaria n. sp. (*saratogaensis*)[1]

The foregoing fauna has been placed as Miocene by Mrs. Esther Richards Applin because of its stratigraphic position, overlying the Oligocene found below, and because of the absolute difference in the faunas found, probably indicating a considerable time-break between their deposition.

From a depth of 2,177–87 feet

Discorbis bertheloti var.
Amphistegina lessoni var.
Truncatulina americana var.

According to Mrs. Applin, these forms are common to and characteristic of the uppermost or *Discorbis* zone of the Middle Oligocene.

FOSSILS FROM 2,060 TO 2,093 FEET IN GULF PRODUCTION COMPANY—TEEL NO. 2

Cytheritsis cf. *ashermani*
Nonionina scapha
Globigerina bulloides var.
Amphistegina lessonii (young)
Polystomella sp.
Pulvinulina texana
Nonionina scapha var.
Truncatulina americana var.

These are classified by Mrs. Applin as of Oligocene age.

Peculiar concretions from Saratoga wells.—A considerable quantity

[1] Manuscript names of undescribed species.

of oölitic barite has been bailed from certain Saratoga wells. It is described by E. S. Moore[1] as follows:

The concretions take several different forms. Some of those from a well 1,350 feet deep, at Saratoga, are pisolitic, as they consist of concentric spheres and are from 3 to 5 mm. in diameter. They are of a dirty-white color. Other samples show irregular structures and the material is porous, somewhat like very fine-textured pumice in appearance, and this type was found in wells in both areas. In some cases the structures take the form of rings and resemble travertine, which has been deposited around stems or roots of trees.

The most interesting type, however, came from a well at Saratoga at a depth of 1,130 feet. These are large oölites ranging in size from 1.25 to 3 mm. in diameter and varying in shape from nearly perfect concentric spheres to ovoids. In thin-section they usually show a great number of extremely fine lines marking the outlines of the spheres. The mineral is cryptocrystalline to amorphous and somewhat opalescent in appearance.

In the center of the oölite there is generally an area of irregular shape occupied by material which is more porous than that surrounding it and it is not concentrically arranged. It consists of an earthy mass, sometimes slightly stained with iron oxide, with extremely small crystals of what seems to be barite arranged along open spaces and mixed with the earthy material. It is possible that some of these crystals are barium-orthoclase, as the optical properties correspond to those of that mineral. The interference colors are bluish gray and the extinction angle is zero or very small. A little calcite was found in two thin-sections and a little quartz in another, while it is believed that a small amount of clay is also present. In four thin-sections examined and in the large number of concretions crushed for purposes of analysis no definite body, such as a sand grain or similar structure, was found serving as a nucleus. Outside of the earthy, central mass the material is concentrically arranged and the spheres marked by very fine lines. It appears that the concretions began to form by deposition of barite in both a crystalline and earthy condition, with small amounts of other minerals, and that this later continued to precipitate more rapidly in a purer condition, either as a replacement of some other mineral or in open spaces in the sand. No evidence of replacement is found unless it be the traces of calcite existing in some oölites, as the concretions are loose and not embedded in a solid rock.

In color the oölites are white to bluish gray, and they are very smooth on the outer surface. From their appearance they were at first thought to be chert concretions, but an examination showed a specific gravity of 4.25 and a flame coloration for barium, strontium, and a trace of potassium.

The Saratoga barite somewhat resembles that from Montana in color and form, but it is distinctly oölitic or pisolitic, and it is partly cryptocrystalline to amorphous.

[1] E. S. Moore, "Oolitic and Pisolitic Barite from the Saratoga Oil Field, Texas," *Geol. Soc. Amer. Bull.*, Vol. 25, pp. 77–79.

As stated above, the flame test indicated barium, strontium, and a trace of potassium. A chemical analysis made by Mr. L. J. Youngs, of the Department of Geology and Mineralogy of the Pennsylvania State College, to whom I am indebted for these figures, shows the following percentages:

SiO_2	0.98	SO_3	35.104
Al_2O_3	0.41	H_2O	0.55
FE_2O_3	0.07	Vol. matter	
CaO	2.129	$BaSO_4$	88.54
SrO	2.067	$SrSO_4$	3.76
BaO	58.17	$CaSO_4$	5.17

In discussing this matter with Mr. E. G. Woodruff, he stated that at least some of these concretions undoubtedly formed in the wells after they were equipped, because they had been found reaching a quarter of an inch in diameter, in a well with a screen on the tubing, the mesh of which was altogether too small to admit a concretion of the size stated. . . . . When a nucleus is present it consists of earthy material made up mostly of clay and barite and this mass is often stained with iron oxide which gives the center of the concretion a brownish tint.

This additional information is interesting from the standpoint of its bearing on the origin of concretions. It would be practically impossible for bacteria or other low types of life, which are believed to play an important part in the origin of oölites, to exist in a liquid with such strong antiseptic qualities as those of warm petroleum containing considerable sulphuric acid. It would seem to demonstrate that living organisms are not essential to the development of oölites and that these may form where precipitation is taking place in an agitated solution, in the absence of life.

Oil and gas.—The oil and gas at Saratoga is very irregular in its occurrence, and correlation from well to well is extremely difficult. On account of local cementation of sand layers into hard, limy sandstones logged as "rock," great difficulty is experienced if one tries to correlate on rock strata. Logs of wells drilled very close together vary considerably as is evidenced by wells Nos. 295 and 288 of the Rio Bravo Oil Company. These wells are only 30 feet apart and yet their logs are entirely dissimilar. From a study of logs one could easily jump to the geologist's stock conclusion that the dissimilarity was all due to the rotary system of drilling and the drillers; but the writer's close observation of the field over a period of about eleven years leads to the conclusion that the drillers' logs are reliable. There is so much difference in the way that sand, shale, gumbo, and rock drill that a driller would have to be most ignorant and careless to make large errors in his log. All drillers for the Rio Bravo Oil Company

log changes in formation accurately as soon as they have gone from one formation into another. The conclusion reached is that there is a marked lensing or change in formation laterally at Saratoga and the oil is found in certain zones, and that accumulation is governed in some cases by this phenomenon. This condition and the occurrence of water, oil, and gas at Saratoga is very well described by Fenneman[1] as follows:

While any one bed, whatever its composition, may pass laterally into a bed of any other composition, and the drill is therefore liable to encounter almost any material at almost any depth, there are certain horizons which are characterized by a large predominance of one kind of material. As an illustration of this, there is in almost all of the wells in the southwestern part of the field sand or gravel, or both, at a depth approximating 500 feet. That this occurrence represents merely a horizon abounding in local sands and gravels and not one continuous stratum is plain from the diversity in thickness, number of beds, and depth reported. Thicknesses vary from a few feet to more than a hundred. In one well there may be but a single bed of great thickness; in another near by the sands or gravels at approximately the same horizon may appear in half a dozen beds separated by intervening clays. The minor diversities of depth would require that any scheme of correlation should hypothesize sharp folding of these unconsolidated sediments. In the same part of the field [the southwest], depths between 800 and 900 feet generally show sands to which the description given above would apply. In at least a small part of this quarter of the field a thick sand has been found in all the deep wells between 1,400 and 1,500 feet. It is possible that this sand is a single and well-defined bed. In the northern part of the field sands have been found quite generally at depths between 900 and 1,000 feet. Above this sandy horizon, for a thickness of from 200 to 400 feet, little sand is found, the sediment being almost entirely clay. The same is true of the 100 or 200 feet of sediments overlying the sandy zone found at a depth of 800 feet in the southwestern part of the field.

While the sandy zones here described are not to be understood as continuous strata, but rather as large thicknesses within which limited beds of sand are very frequent, it may still be true that these small beds are so thickly crowded as to afford continuous passage for fluids [Fig. 5]. For example, it seems certain that in the southwestern part of the field the 500-foot horizon of sands and gravels is for all practical purposes an artesian stratum. It is, however, distinguished from an artesian stratum, strictly so-called, by the fact that its varying depths at different places do not indicate dips of the beds. This being the case, it is impossible to infer from even a large list of depths, however carefully correlated, what the depth of the sand might be at any other place, however near.

[1] *Op. cit.*, pp. 58–60.

Showings of oil are found at almost any depth and at irregular intervals. There is no considerable thickness of sediment which does not in some part of the field afford a showing of oil or gas. In the southwest quarter of the field oil in commercial quantities has generally been found in the sands at a depth of 800 or 900 feet. The deeper oil, which has been obtained from a small spot in this part of the field, is found in the thick bed of fine sand encountered at a somewhat uniform depth of about 1,400 feet. In the northern part of the field most of the oil has been found between 900 and 1,000 feet deep. In each case the almost complete absence of sands from the next higher clays has given to the latter the character and function of a cap rock.

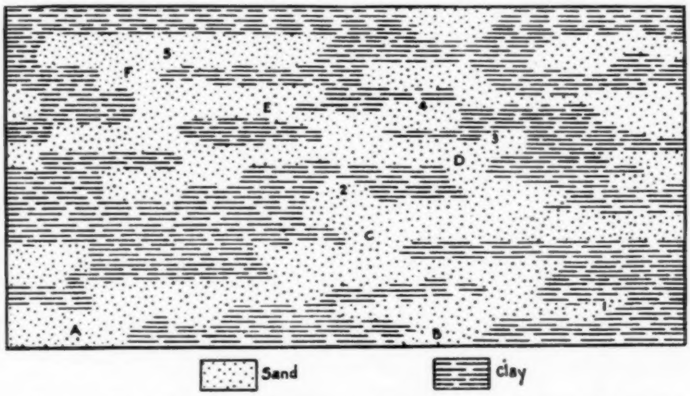


FIG. 5.—Illustration (after Fenneman) showing accumulation of oil in sandy zones in beds having little dip.

Ideal section of irregularly interbedded sands and clays. Oil may be borne up from *A* and *B* past *C*, *D*, *E*, and *F*, accumulating at 1, 2, 3, 4, and 5. The proportion of clay may be much larger than here represented, and the motion of the fluids may be more nearly horizontal.

The oil in this field is not generally accompanied by the large amount of gas found in the rock wells of Spindletop, Sour Lake and Batson. With the exception of a few wells, gushing has been of a milder type than that of the other fields named. However, while gas does not usually accompany the oil in large quantities, it is abundantly present in separate bodies. No field in Texas (Humble excepted) has furnished such spectacular blowouts as Saratoga. Generally the beds from which these violent eruptions have occurred are in the upper half of the well section; that is, above the clay zone which overlies the oil. In the northern part of the field large quantities of gas were found at about 500 feet. In the Rio Bravo No. 215 there were blowouts from depths of 200 and 600 feet. The same company's Well No. 211 probably furnished the most violent

example. A pocket of gas was struck at approximately 500 feet, giving rise to a blowout so violent that the surrounding ground was affected by cracks to a distance of 250 feet. From these cracks there were eruptions of mud at distances of at least 200 feet from the mouth of the well. A crater was formed a few rods in diameter and more than 20 feet deep. The machinery and the wreck of the derrick were swallowed. The danger of such occurrences was for a time one of the chief difficulties in drilling in this field. At least one similar blowout, though less violent, occurred from the 1,400-foot sand, or at about that depth.

The ground waters of this field are fresh to a much greater depth than those of the other Hardin County fields. The strong flow usually met at a depth of about 500 feet in the southwestern part of the field is always reported as fresh. It appears that, by ill fortune or carelessness, this water was not properly cased off in certain wells. When the wells were drilled through the underlying clay, this water was given access to the sandy zone containing the oil and soon appeared in other wells, which had been pumping oil alone. The admixture of this water was the more unfortunate on account of the fact that fresh water is separated from the oil with greater difficulty than salt water.

Below the level of the clay zone which overlies the first important oil the water encountered is salt. The amount of salt water pumped previous to the drilling of the deep wells was small. The 1,400-foot sand, after yielding oil abundantly for a few weeks, began to produce large quantities of salt water.

All the production obtained at Saratoga has come from sands lying above the cap rock. This is in marked contrast to Spindletop, Sour Lake, and Humble where the early gushers and a large percentage of the early production was obtained from the porous limestone or dolomite designated as cap rock. In all cases where the cap rock has been tested at Saratoga it has yielded only hot black sulphur and salt water, in some cases carrying a very small showing of oil. The warmest water measured by the writer was from 1,600 feet depth and had a temperature of 115° F.

In comparison with other Gulf Coast fields the Saratoga oil is rather heavy. The specific gravity varies from 15° to 22° A.P.I., according to the depth at which it is found, the gravity at depth being about as follows:

600– 800 ft.	15°–16° A.P.I.
800–1,000 ft.	17°–18° A.P.I.
1,100–1,500 ft.	19°–22° A.P.I.
1,500–1,900 ft.	22°–26° A.P.I.

There are, however, certain rare, freak wells of shallow depth in the field which have yielded oil up to 26° A.P.I.

The Saratoga oil in common with all Gulf Coast crude is of neither a paraffin nor asphalt base, if these terms are allowable, but is of a neutral or napthene base. This crude runs extremely high in zero cold test lubricants as the following analyses show:

ANALYSIS OF PETROLEUM FROM SARATOGA, TEXAS

Physical characteristics:	
Color	Black
Odor	Strong H_2S
Specific gravity	18.4 A.P.I.
Flash	230° F.
Sulphur	0.835%
Commercial product (by Sinclair Oil and Gas Co.):	
Gas oil	28.0%
Lubricant stock	29.0%
Fuel	39.0%
Loss	4.0%
	100.00%
Commercial product (by Rio Bravo Oil Co.):	
Gas oil	40.4%
Finished lubricant	31.6%
Fuel	19.6%
Loss	8.4%
	100.00%

The average 18° A.P.I. Saratoga crude is conceded to be equal to any in the Gulf Coast in amount of lubricants recovered, but the high sulphur content causes some trouble in the refining.

PRODUCTION

Up to the end of 1923, about 884 wells had been drilled at Saratoga on 672 acres. From this drilling 22,861,841 barrels have been recovered, or 34,000 barrels per acre and 25,800 barrels per well. On the Rio Bravo Oil Company property 7,142,642 barrels have been recovered by drilling 184 wells on 272.7 acres, or 31,500 barrels per acre and 38,800 barrels per well. Mr. Charles Paggi[1] states that the Teel 1-acre tract located in the northern part of the Cotton survey has produced to date about 300,000 barrels of oil. This is not high recovery for the Gulf Coast country but it shows what can be expect-

[1] Private communication.

ed from a field which has never had cap-rock gusher production or deep-flank gusher production.

One of the saving graces of the Saratoga field has been that although one never knows when starting a well where he will find a good sand or how much initial production to expect, he can usually count on the expense of drilling being fairly low. Out of 184 wells drilled by the Rio Bravo Oil Company since 1903, the average cost per well has been $4,760. Wells 1,000 feet deep have been drilled completely equipped for pumping, including casing, strainer, rods, and tubing, at a cost as low as $1,600. The average cost for a completely equipped 1,400-foot well prior to 1914 was about $3,500. Of the 184 wells drilled by the Rio Bravo Oil Company, the average initial production was 110 barrels; the highest initial production, 3,700 barrels; and the lowest, 3 barrels. Of the 184 wells drilled by the Rio Bravo Oil Company, only 11 have been dry holes.

All drilling is done by the rotary system. When not cemented into sandstone the upper 500 feet or so of Columbia and Lafayette sands and gravels drill very easily, and it is not at all uncommon for a drilling crew to make 300–450 feet of hole in the first day's drilling. It is also not at all uncommon to drill and complete a well to the 800-foot sand in seven or eight days. When the upper sands are cemented and hard, the drilling is slower. It is of interest to note that some of the earliest coring with the rotary was done here in 1905. As rock bits had not been invented, it was common practice to use a plain slotted-end core barrel and adamantine. Cores 10 and 12 inches in diameter were removed. After coring, the rock drilling in the softer formations with fish-tail bit was resumed.

The present practice is to drill an 8-inch hole down to a tough gumbo stratum lying just above the zone in which oil is expected. Ordinary 6-inch line pipe is landed for casing and a formation shut-off made. The hole is usually bailed to test for shut-off, and these tests are usually satisfactory. No instances are known of any water strings ever having been cemented at Saratoga. After the testing for the shut-off, drilling is resumed with $5\frac{7}{8}$-inch fishtail bits. The first sandy zone encountered is watched closely for oil content. Oil is usually found in what is logged as "sand and shale." If the first sands encountered seem to be water sands, drilling is continued until an oil sand is encountered. Usually 50 or 60 feet of the oil-bearing

sand and shale is desired. As soon as enough of this formation has been encountered to make it fairly certain that some kind of a well will be obtained, the drilling is stopped and strainer is set. The strainer string is usually the 4- or $4\frac{1}{2}$-inch size.

If a water sand is thought to be present above the oil sand to be tested and below the bottom of the 6-inch casing, a canvas "boot-leg" packer is run on the strainer string preferably to come opposite a layer of gumbo. The object of this boot-leg packer is to make a shut-off between the supposed water sand and the supposed oil sand. It is really remarkable how often this method of shutting off water is successful.

The strainer string contains the strainer to be set opposite the oil sand, the boot-leg packers, and on the bottom a back-pressure valve and a wash plug. Wash pipe, usually 2-inch size, is placed inside the strainer with a wash ring at the top. It is run into the hole and held about 2 feet off bottom. The hole is then washed with clear water to remove drill mud from the face of the oil sand, and after washing operations are finished the pipe is set down on bottom. The wash pipe is then fished out and the hole bailed. If the gas pressure is not strong a great deal of bailing may be necessary. Sometimes a well may be bailed for a week or so before it comes in. Wells good for 200 or 300 barrels will usually flow some as soon as bailed down.

The sands in the Gulf Coast fields are usually soft and fine grained. This necessitates setting of very fine strainer. The average strainer set has openings between the wire for admission of fluid of only .012 inches width. The three sizes of strainer most commonly used are as follows:

Layne & Bowler	McEvoy	Getty (Mesh)	Width of Opening in Inches
.012	12	50	.012
.010	10	60	.010
.009	9	70	.009

Of late years it has become common practice to run the 4-inch strainer string up into the 6-inch casing only 50 or 60 feet. In this case a canvas adapter packer is set between the 4-inch and 6-inch

to make sure that water does not enter the well between them. The strainer-string containing this packer is run in on the drill stem with setting tool attached. After washing and setting the packer, the drill stem is pulled and the wash pipe comes out with it.

It sometimes happens that where 50 or 60 feet of strainer has been set the bailing will show nothing but salt water. In such cases it is customary to cement off the bottom of the setting 5 or 10 feet at a time to see if the water is bottom water. This is often a successful operation and many good wells have been made in this manner.

Frequently after completing a well as dry it is decided that there are sands behind the water string which should have been tested. This condition often arises after a well goes dry which has been pumping for ten or twelve years. If the well has but recently been completed, it is customary to drop a whip-stock in the hole and mill through the 6-inch pipe about 50 feet above the point where it is desired to test. A $5\frac{7}{8}$-inch hole is then made down to the sand and strainer set in the customary manner, using plenty of boot-leg packers. In an old well where the mud behind the pipe has had a chance to settle for several years, it is customary to perforate the water string opposite the sand. Remarkable results are frequently obtained in this manner. For instance, well No. 212 B.B.B. & C., of the Rio Bravo Oil Company, was drilled to a depth of 1,057 feet in May, 1904, and had an initial production of 119 barrels. In 1914 the production had declined to 1 barrel per day and it was decided to perforate the 6-inch casing opposite a sand logged from 850 to 865 feet. This was done and the well started off with 60 barrels per day initial production of 17° A.P.I. gravity oil and no water.

In carrying on repair work the 4-inch strainer string is often perforated in places where no strainer was set. This sometimes gives good results. In fact, when a well gets down to the point where abandonment is necessary, it is usually perforated opposite all logged sands below 600 feet before it is given up as hopeless. In addition, there are some instances where the perforating or ripping of old strainer has been extremely successful. After perforating operations an attempt is first made to pump the well without setting strainer. If the sand bothers too much, $2\frac{1}{2}$- or 3-inch strainer must be set inside the old 4-inch.

It is common practice on the Gulf Coast to deepen a well by drilling out the wash plug and back-pressure valve set on the 4-inch strainer string. Two-inch drill stem is used in this work. The well is deepened until new sands are picked up and a $2\frac{1}{2}$-inch strainer is set through the 4-inch opposite the lower sands. Sufficient packers are used in this setting to pack off fluid which might enter the hole from the 4-inch strainer.

While drilling costs at Saratoga are relatively low, the pumping costs are high, due to the large amount of sand which comes into the wells sooner or later. This necessitates frequent pulling of rods, frequent replacement of pumping equipment, and the using of special material. The lifting cost is also high because of the small amount of oil produced per well and the large amount of water which the wells make and which must be handled by the pumping equipment. The average lifting costs in cents per barrel for the Rio Bravo Oil Company since 1905 have been as follows:[1]

	Cents per Barrel
1905	4.38
1906	6.21
1907	8.91
1908	11.07
1909	15.34
1910	16.03
1911	14.43
1912	14.70
1913	22.87
1914	20.97
1915	22.39
1916	23.13
1917	18.13
1918	41.01
1919	45.68
1920	77.06
1921	64.81

The wells now producing in the field average less than six barrels per well. All wells in the field make water and emulsion in varying amounts. The average emulsion reaching the treating plants averages 50–60 per cent water, and in addition to this a large amount of

[1] This item includes the cost of labor and material on pumping wells, cost of superintendence, and cost of collecting oil.

water has probably been bled off at the flow tanks and settling tanks before the oil is pumped to the treating plants.

The Saratoga emulsion is very hard to treat, and considerable trouble is experienced in removing the water. Some of the production is treated by electric dehydration but the greater percentage is treated by steam heat to remove the water.

ACKNOWLEDGMENTS

This paper is based on a close study of the Saratoga field during the past eleven years. The author has drawn also on such published data as could be used.

GOOSE CREEK OIL FIELD, HARRIS COUNTY, TEXAS

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Houston, Texas

ABSTRACT

The Goose Creek oil field in Harris County, Texas, first received attention in 1906, when its possibilities as an oil field were recognized by Mr. L. P. Garrett and Mr. Lee Hager, independently of each other. To these gentlemen credit is due for the discovery, although commercial production was not obtained until after much drilling by numerous enterprises. The stratigraphy is characterized by the unconsolidated nature of the sand, gumbos, and shales, which are penetrated in drilling to a depth of 5,000 feet. The structure at Goose Creek is a low dome, with no evidence of any salt core or salt plug such as distinguish most Gulf Coast fields. The field has produced about 50,000,000 barrels of oil from about 1,000 acres, production coming from sands at depths of from 1,000 feet to 4,200 feet. Recent subsidence of the surface over the producing area is explained by the removal of oil, gas, water, and sand, which permits a closer orientation of the sand grains in the producing horizons.

LOCATION

The Goose Creek field is located in the southeast corner of Harris County, Texas, approximately 25 miles southeast of Houston, on San Jacinto Bay. The field was accessible only by water or dirt road until 1917, when a spur, known as the Goose Creek & Dayton Railroad, was built from the main line of the Southern Pacific at Dayton, Texas, to the town of Goose Creek.

HISTORY

In 1906, a fishing party, composed of Messrs. L. P. Garrett, R. A. Welsh, and R. T. Rue, noticed the occurrence of gas seeps in the vicinity of Goose Creek. The men composing this party understood fully the significance of these indications, and a careful investigation resulted in the location of numerous gas seeps and paraffin beds over the area which is now the Goose Creek oil field.

Satisfied that the indications warranted exploitation, Messrs. Welsh and Rue formed the Goose Creek Production Company and proceeded to procure leases upon the land surrounding Goose Creek. Upon examining the records, it was found that Mr. Lee Hager had already secured leases upon the Sweet and Briggs properties. Evidently, he too had observed the indications and satisfied himself with the possibilities of the prospect, as he has consistently done at

nearly every coastal dome. The remaining lands were blocked up in the name of the Goose Creek Production Company.

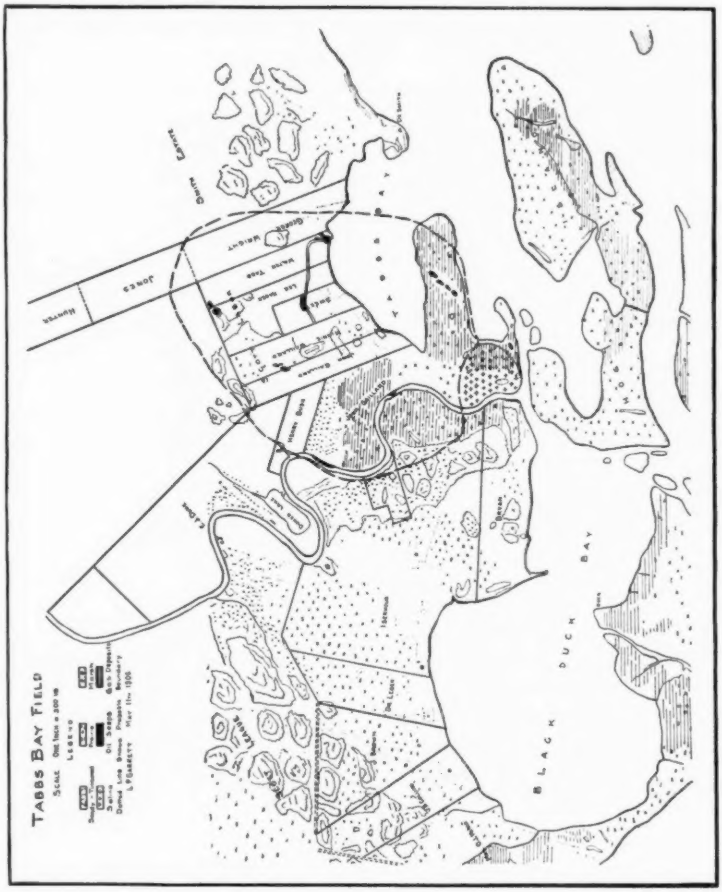

FIG. 1.—A map of Goose Creek field made by Mr. L. P. Garrett prior to discovery

At this time, 1907, Mr. L. P. Garrett, employed by the Rio Bravo Oil Company, made the first favorable report to his company upon the possibilities of Goose Creek becoming an oil field. Accompanying this report was the first map of this area (Fig. 1), which shows the

location of gas seeps and paraffin beds, together with the outline of the probable area of production. The productive area delineated by Mr. Garrett on this map coincides very closely with the field as it exists today, and certainly he is to be commended upon the accurate interpretation of the meager indications found in 1907, which has led to the development of one of the Gulf Coast's greatest producing oil fields.

It has been learned from reliable sources that at about this time Mr. Patillo Higgins had observed the presence of gas emanations in this territory. It is thought, however, that he had seen the gas seeps in the vicinity of Hog Island. What significance he attached to it, the writer has been unable to learn.

DEVELOPMENT

The Goose Creek Development Company commenced drilling the first well in December, 1907. This well was located on the J. Gaillard tract, only a short distance north of the old John Gaillard home, midway between the farthest north-and-south and east-and-west gas seeps. At a depth of 700 feet a showing of oil was encountered, but drilling was continued. At the end of two years, the drill had reached the depth of 1,700 feet and the well was abandoned. In June, 1908, the Goose Creek Production Company started their second well. It was also located on the Gaillard land, and very near what was known as the Rucker 4-acre tract. This well was completed as an 800-barrel well at a depth of 1,600 feet, the first to produce oil in the Goose Creek field.

In 1909, the Goose Creek Production Company sold their entire holdings to the Producers Oil Company, the consideration being $50,000 in cash and a one-fourth overriding royalty. During the next few years the Producers Oil Company drilled ten or fifteen wells.

The results of these tests were very discouraging, and the Producers Oil Company surrendered the leases to the original holders. In a short time thereafter, the leases found their way into the hands of various oil companies, wildcatters, and speculators. The area, drilled full of dry holes, with an occasional small pumper, struggled along under the shadow of its past disappointments for six years.

On August 22, 1916, the American Production Company, drilling on the Gaillard tract, 600 feet north of the shallow production, and financially "on their last legs," encountered a sand at 2,030 feet. The bit had hardly penetrated the sand when the well came in flowing wild, at a rate estimated to be 10,000 barrels per day. This spectacular discovery inaugurated a period of active development, which has continued up to the present time. Prior to the discovery of the 2,000-foot sand, practically all of the production was obtained from sands lying at shallower depths. Several wells had been drilled to greater depths than 2,000 feet before the American Production Company's discovery, but practically all of these were located beyond the productive limits of this sand.

During this period of development at Goose Creek, several exceptional wells were completed. The Simms Oil Company brought in their Sweet No. 11 in August, 1917, from a depth of 3,027 feet, the well flowing wild for several days, at the rate of 35,000 barrels of oil per day, with a great amount of sand. Finally it sanded up, leaving the surrounding area covered with a blanket of oil-saturated sand and mud 1 to 3 feet in thickness. The Humble Stateland No. 10 was completed November 10, 1922, at 4,292 feet, with an initial production of 3,200 barrels, and has produced approximately 1,000,000 barrels of oil to date and is still flowing at the rate of 1,200 barrels per day. The Gulf Production Company's Chapman-Bryan No. 1, still flowing at the rate of 900 barrels per day, was completed March 30, 1922, at a depth of 4,200 feet. This well has produced 1,237,000 barrels of oil to date.

It will be seen from the production curve (Fig. 2), that the production of the field gradually climbed from 42,000 barrels in 1916 to over 9,000,000 barrels in 1918, where the peak of production was reached. The decline in production has been very irregular, rising as the deeper sands were developed, and falling as the flush production was given up. At the present time, the production is on the decline slope, and has nearly reached the point where the curve tends to approach the horizontal. Its projection into the future is conjectural, but undoubtedly the beams will be running at Goose Creek for a good many years to come, as evidenced by Spindletop, with its single horizon still producing 1,000 barrels daily after twenty-three years.

TOPOGRAPHY

At Goose Creek there is no topographical elevation or depression to indicate the presence of a dome, and only the closest observation and the greatest perseverance led to the discovery of its treasures.

STRATIGRAPHY

A well, drilled in the center of the field, encounters the following strata: The first 50 to 100 feet is composed of soft surface sands and

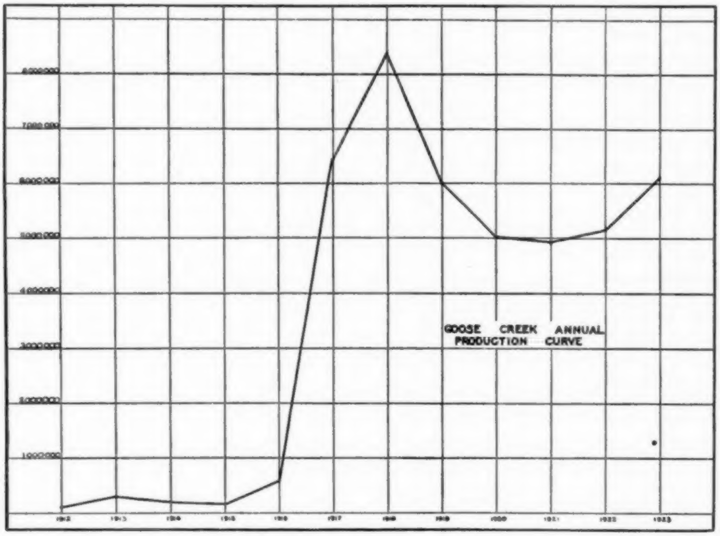

FIG. 2.—Curve of annual production, Goose Creek oil field

clays of recent deposition. The bit then enters red, gray, blue, and brown shales, and clays intermittently separated by strata of water sands, belonging to the Pliocene. At a depth of approximately 1,000 feet the first oil sand is encountered. Below this, the predominating color of the shales and clays is still red and pink, but the sands are harder and carry an abundance of brackish water. From 2,300 to 2,600 feet a horizon made up of alternating sandstones, sands, gumbos, and shales is encountered. The majority of the sands carry oil, but occasionally a stray water sand occurs, causing the usual

trouble in the completion of an oil well. Below this producing horizon, numerous water sands, approximately as salty as sea water and separated by red and blue gumbo, are passed through. The next producing zone extends from 2,800 to 3,100 feet. In this zone, the sands are probably thicker than in any other producing horizon, at places attaining a thickness of 80 to 100 feet, and they are of greater areal extent than any other producing sands in the field.

At 3,300 feet and again at 3,600 feet, sands are passed through which have furnished exceedingly good wells. Below this depth, the formations take on a darker hue, the shales and gumbos having changed from blue, pink, and red to dark blue and dark gray. At just what depth one passes from Miocene to Oligocene is not definitely known, but it is evident from fossils obtained that the production above 3,900 feet is not older than Miocene.

For the next few hundred feet, an almost unbroken series of dark shales is found, and at 4,200 feet the deepest producing sand is reached. This producing horizon is really a sandy phase of the shales, rather than a true sand stratum. At this depth, paleontologists report Oligocene fossils. The oil is lighter in gravity, the waters are more than twice as salty as sea water, and the sand is very irregular in its areal extent. There appear to be a series of sand lenses, which lie promiscuously here and there under the field, failing entirely in certain localities and thickening to 30 or 40 feet in others.

What Goose Creek holds in store below this depth, can be revealed only by the drill. However, if this field is a true salt dome, and so far there is nothing to indicate that it is not, the possibilities for deeper production should be exhausted only when the salt core itself is encountered. The following deep wells have already been drilled without success:

Gulf Production Company, John Gaillard Fee No. 15, to 5,002 feet
Gulf Production Company, Beaumont Petroleum Company No. 23, to 5,000 feet
Gulf Production Company, Isenhour No 6, to 4,833 feet
Gulf Coast Oil Corporation, Gaillard No. 35, to 4,781 feet
Humble Oil and Refining Company, Gaillard No. 48, to 4,708 feet

Experience in the salt-dome territory has taught that in many cases a dry hole in a proven field condemns only a very small area surrounding the well itself.

STRUCTURE

We have not sufficient data to determine when the subterranean agencies began their movement in this locality, but it is evident that

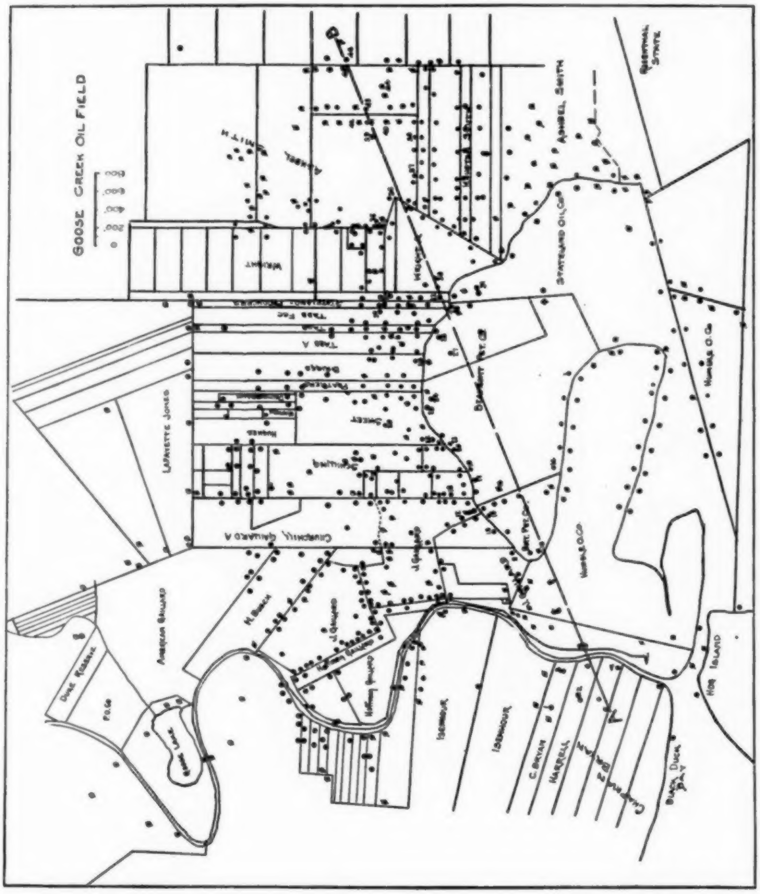

FIG. 3.—Map showing location of wells, Goose Creek oil field

the movement was still in effect as late as Pliocene time. Whatever this force may have been, the upward intrusion of the salt core, or the crystallization and deposition of salt by ascending waters, the resultant force must have been upward, elevating the beds and form-

FIG. 3.—Map showing location of wells, Goose Creek oil field

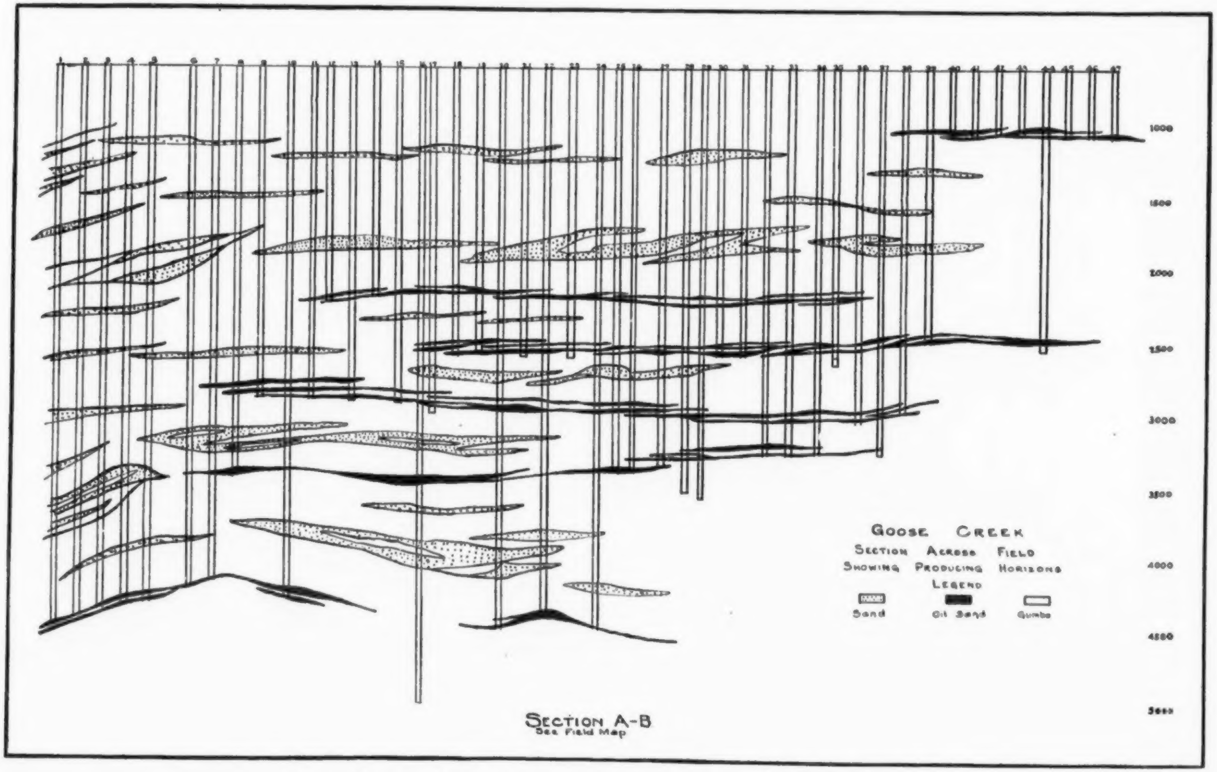

FIG. 4.—Map showing northeast-southwest section across Goose Creek oil field

ing a circular reservoir, which has proved very efficient for the accumulation of petroleum. This force was of such magnitude that it has evidently destroyed, to a great extent, the continuity of the soft unconsolidated beds, leaving the sands and clays in irregular masses and lenses, and accounting in a way for the difference in thickness and character of the formations, and also in the variation in production of adjacent wells. The cross-section of the field (Fig. 4) gives an idea of the various producing horizons, and also shows the lenticular nature of the sands.

Detailed correlation in this field is very difficult on account of the lack of continuity of the beds, and can be arrived at only in a general way. There is, however, a marked dip to the east from the Wright "A" lease, extending eastward through the Houston-Smith lease. A pronounced north dip becomes evident a few hundred feet south of the south line of the Jones tract, forming the northern flank of a gentle arch, which extends to the south through the field and terminates in a very gentle dip to the south, in the vicinity of Hog Island.

The thought is ever present that Goose Creek, Edgerly, Orange, and Welsh, having no known salt cores, might be classed as true domes independent of salt-dome movement. This is a subject too broad to be discussed in this paper, but it may be said that in every case these fields have taken on the typical circular form of the salt dome. The position of the basal Oligocene at both Goose Creek and Orange indicates a vertical uplift of several hundred feet at these localities, a much greater displacement than revealed in the structure of the overlying strata.

The salt waters in these fields increase uniformly with depth. This might also be true in any area, but in no area outside the salt-dome fields does the salt content equal 12 per cent, which is attained at both Goose Greek and Orange. In fields of the Goose Creek, or deep-seated, type, it has been observed that below 1,000 feet the waters increase in salinity at the rate of 1 per cent salt for every 180 feet of depth.

CHARACTER OF OIL

The oil produced at Goose Creek is of a dark green color, ranging in gravity from 22° to 27° Baumé, and possessing the odor of cedar rather than the hydrogen-sulphide odor so characteristic of the cap-

rock fields. Practically all of the producing sands above 3,600 feet produce an oil varying in gravity from 22° to 24° Baumé, while the sands below this depth produce a lighter, or 26° to 27° Baumé oil. A refining test of a typical Goose Creek oil is given in Table I.

TABLE I

ANALYSIS OF GOOSE CREEK CRUDE OIL

Gravity: 23.2 Color: Dark green
Sulphur: 0.117 Boiling-point: 420

Per Cent	Degrees Fahrenheit	Gravity Baumé
10	464	32.5
20	510	30.2
30	548	28.5
40	586	26.9
50	630	25.5
60	684	24.2
70	700	23.8
80	704	24.6

PRODUCTION STATISTICS

At the close of 1923, Goose Creek had produced a total of 47,760,000 barrels, and in Figure 2 is shown the production curve for the entire field, from the year 1912 to January 1, 1924. The total productive area at present consists of approximately 880 acres, giving an average total production to date of 54,272 barrels per acre, with the field still producing 13,500 barrels per day.

DRILLING METHODS

The rotary method of drilling is exclusively used in this field. It is the general practice to set from 400 to 800 feet of surface 10-inch casing. A $9\frac{7}{8}$-inch hole is then carried to the last gumbo above the sand to be tested. If this depth is not known, a rat-hole, or small hole, is carried in advance of the larger hole, until the sand is encountered. The hole is then reamed to the last gumbo above the pay, and 6-inch casing set. Drilling is then resumed with $5\frac{7}{8}$-inch bit. When the hole is drilled into the sand to the desired depth, $4\frac{1}{2}$-inch liner and screen is set, the liner being sealed well up in the 6-inch casing. In wells located in the bay, as a rule, a few joints of surface $15\frac{1}{2}$-inch casing is set, followed by 500 to 1,000 feet of 10-inch. The hole is then com-

pleted as described above. Cementing of casing is not common, as a water-tight seat is usually assured by virtue of the tough, plastic nature of the gumbo and also by the cavey character of the overlying beds, which, immediately upon the cessation of the mud circulation, close in against the casing.

The deepening, re-working, sidetracking, and plugging back of wells is common in Goose Creek, general rotary practice governing these operations. Coring of the sands was begun at Goose Creek in 1915. Prior to this time, practically no coring was attempted. Oil sands were indicated by the showing on the ditch, or by cuttings caught in a receptacle at the mouth of the flow pipe, and it was believed that an oil sand which would not show oil on the ditch was not worth testing. This belief has undoubtedly often been responsible for failures where a good oil well might otherwise have been completed. The coring device generally used is a short piece of 3- or 4-inch pipe, toothed at one end, and is commonly known as a basket, or barrel. This barrel is screwed to the drill stem and lowered into the well, where it is rotated as an ordinary bit, with just sufficient weight upon the teeth to allow them to cut their way into the formation. When the desired length of core is drilled, the weight upon the teeth is increased, causing them to fold in toward the center, thus completely encasing the core. The drill stem is then pulled from the well, the teeth sawed off, and the core examined and analyzed to ascertain its oil or salt-water content.

Goose Creek is the most modernly equipped field in the Coastal district. Plants of the various companies supply electrical power for the pumping of wells, treating of oil, etc. Practically every well in the field is pumped by electric power. The Gulf Production Company has a 1,500-kilowatt plant located in the field. The Humble Oil and Refining Company supply power to the field from their Baytown plant.

The drilling cost of wells at Goose Creek has averaged approximately $10 per foot for wells 2,400 to 3,500 feet deep. At the close of 1923, in the neighborhood of 900 wells had been drilled within the comparatively small area of 880 acres, with an average production of 53,000 barrels per well.

SUBSIDENCE OF SURFACE OVER PRODUCTION AREA

Since the active development of Goose Creek in 1916, there has been a marked subsidence of the area lying over the center of the field. During the years 1916 and 1917, the surface of Gaillard Peninsula (as it was then known) was a land area which stood $\frac{1}{2}$ to 2 feet above the mean high tide. Material was transported to the wells located upon the peninsula over shell and plank roads. Today, this entire land area lies submerged under possibly 3 feet of water. At no place could a subsidence be more clearly noted. In many places, along the north and south limits of the field, miniature faults may be seen plainly, and they may be traced for considerable distances. Recent elevations, compared with those determined by the U. S. Geological Survey of 1916, show the greatest subsidence, of 2.2 to 2.7 feet, to have occurred over the area of greatest production, with the surrounding area gradually resuming its original elevation a short distance beyond the limits of production.

The explanation offered by the writer for this recent land subsidence is that, due to the enormous flow of gas, oil, and water in the wells, a movement or flow of the fluids in the sands caused a readjustment and closer packing of the sand grains. The overlying beds, consisting of comparatively soft clays, shales, and sands, gave way and settled to a lower position because of the readjustment of the underlying sands.

AN EOCENE FAUNA FROM THE MOCTEZUMA RIVER, MEXICO

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Sharon, Massachusetts

ABSTRACT

This short paper describes and figures a number of species of Foraminifera and Ostracoda from material collected on Moctezuma River, in the state of Vera Cruz, Mexico. Eocene deposits were discovered here by Earl Oliver in 1922. A shale characterized by a great abundance of a new Foraminifer of the genus *Operculina*, and having with it a number of species of other Foraminifera and some ostracods, is present.

In 1922 Mr. Earl Oliver, while working in the state of Vera Cruz, Mexico, discovered on the east bank of Moctezuma River, on the eastern portion of the bend which makes its way into Hacienda Romance and near the mouth of the Rio Tamuin, an outcrop of shales which were very rich in Foraminifera. With him I afterward visited this locality and collected material. The shales at this spot are very largely made up of a large *Operculina*, which occurs in great abundance. With it are a few smaller species of Foraminifera and a sprinkling of ostracods, with occasional specimens of one or two species of small planospiral mollusks.

The *Operculina* is closely allied to two species I have described from the lower part of the Upper Eocene of Georgia, which probably very closely places this outcrop in the geologic column.

As some of these species are rather widely distributed on the Atlantic coastal plain of Mexico, it has seemed best to note them and give figures which will serve to identify them. Several of the species show relationships with the Eocene of Europe, and through the ostracods with the Eocene of the coastal plain of Maryland. A description of the species follows:

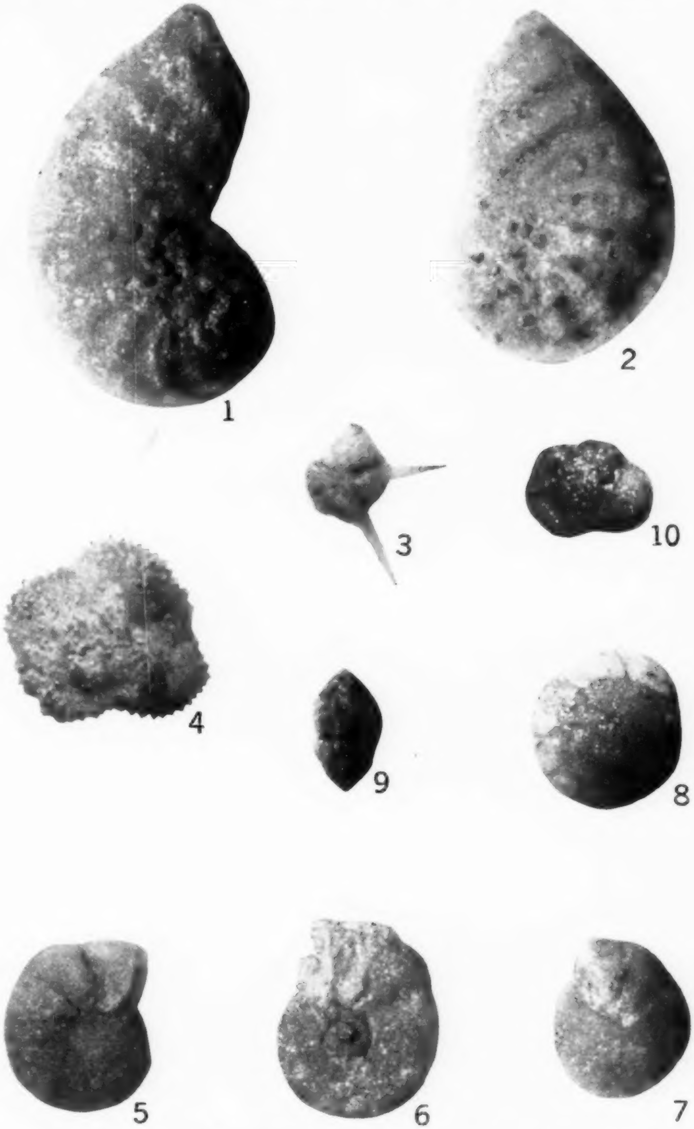
Operculina oliveri Cushman, n. sp.
Plate 6, Figures 1, 2

Test coiled, planospiral, thin, composed of two and a half to three coils, rapidly increasing in breadth; chambers very numerous, as many as thirty-six in the last-formed coil of adult specimens, fairly constant in size and shape, in

1

2

FIG. 1.—*Operculina oliveri* Cushman, n. sp. Side view of exterior, ×6. FIG. 2.—*Operculina oliveri* Cushman, n. sp. Side view of specimen with slightly eroded surface, ×6.



FIGS. 1, 2.—*Cristellaria mexicana* Cushman, n. sp. Side views, ×40. FIG. 3.—*Hantkenina longispina* Cushman. Side view, ×60. FIG. 4.—*Pulvinulina crassata* Cushman, n. sp. Dorsal view, ×60. FIG. 5.—*Anomalina umbonata* Cushman, n. sp. Ventral view, ×60. FIG. 6.—*Anomalina umbonata* Cushman, n. sp. Dorsal view, ×60. FIG. 7.—*Pulvinulina mexicana* Cushman, n. sp. Ventral view, ×60. FIG. 8.—*Pulvinulina mexicana* Cushman, n. sp. Dorsal view, ×60. FIG. 9.—*Bulimina* sp.? Side view, ×60. FIG. 10.—*Truncatulina* sp.? Dorsal view, ×60.

the adult the length of the chamber eight to ten times the height, each chamber gradually increasing in height from the proximal end to the maximum height near the distal end; sutures gently curved until near the periphery, where an abrupt turn backward is made; surface depressed between the sutures, which are somewhat raised above the general surface, but not beaded.

Length of adult specimens, up to 8 millimeters.

Type specimens from the Eocene deposits of the Moctezuma at the second large bend above its entrance into Panuco River, Mexico.

This species belongs in the general group of *Operculina antillea* Cushman, *O. cookei* Cushman, and *O. vaughani* Cushman. It is much smaller than the first, and in many characters is midway between the last two. *O. oliveri*, however, has more chambers in the adult than any of the others, the wall and sutures are thicker, and the whole test heavier than in either *O. cookei* or *O. vaughani*.

At the type locality discovered by Mr. Earl Oliver, after whom the species is named, the specimens are very abundant, making up a large percentage of the shale at that point.

Cristellaria mexicana Cushman, n. sp.
Plate 7, Figures 1, 2

Test biconvex, close coiled except in the adult the last two or three chambers tending to an uncoiled form; periphery keeled except on the uncoiled chambers, which are rounded; chambers numerous, ten to twelve in the last whorl of the close-coiled portion, fairly distinct, sutures raised and limbate, those of the coiled portion broken into coarse beadlike knobs, the sutures of the uncoiled portion more nearly entire; wall thick; apertural face flattened, aperture at the peripheral angle of the last-formed chamber, radiate, slightly protuberant.

Maximum length, 1.50 millimeters; diameter, 0.90 millimeter.

Type specimens from Eocene deposits of Moctezuma River.

This beautifully ornamented species is abundant in the shales containing *Operculina oliveri*. It is in general related to the Eocene species of Europe, such as *Cristellaria fragaria* Gümbel, and those species usually assigned to *C. wetherellei* (Jones), but is distinct in the lesser amount of uncoiling and the much coarser and more broken ornamentation.

Hantkenina longispina Cushman
Plate 7, Figure 3

Hantkenina longispina Cushman, *Proc. U. S. Nat. Mus.*, Vol. 66 (1924), p. 2, Pl. 2, Fig. 4.

Test planospiral, compressed, chambers rapidly increasing in size and height as added, five or six in the adult coil, those of the early coils showing slightly at the umbilicus, each chamber with a long, stout spine, often somewhat longer than the chamber, hollow centered, wall very finely punctate, periphery somewhat lobulate.

This species, already described from the Eocene of Mexico, occurs very sparingly in the Eocene of Moctezuma River.

The genus first figured by Hantken under the name *Siderolina* occurs in the Upper Eocene of Europe and America.

Anomalina umbonata Cushman, n. sp.
Plate 7, Figures 5, 6

Test compressed, plano-convex, dorsal side nearly flat or even slightly concave, ventral side somewhat convex, periphery rounded, about twelve chambers in the last-formed whorl, which is not quite closely coiled, exposing a portion of the earlier whorl at the center of either side; sutures of the last-formed coil distinct, those of the ventral side somewhat depressed, those of the dorsal side limbate and slightly raised above the surface, more or less fused into the central spiral unbonate mass, which is conspicuous on the dorsal side; wall very coarsely punctate; aperture a narrow opening from the periphery along the ventral side about one-third of the way on the inner margin of the last-formed chamber.

Diameter, 0.50–0.60 millimeter.

Type specimens from the Eocene of Moctezuma River.

This is a striking species with its raised sutures, central umbonate ornamentation, coarsely punctate surface, and concave upper surface.

Pulvinulina mexicana Cushman, n. sp.
Plate 7, Figures 7, 8

Test unequally biconvex, dorsal side forming a low cone, ventral side only slightly biconvex, periphery subacute, subcarinate, last-formed coil with eight to ten chambers, only those of the last-formed coil visible from the ventral side, which is umbonate; sutures distinct, very slightly limbate on the dorsal side, ventrally very slightly depressed near the periphery, becoming limbate near the umbilicus, and often fusing on the inner margin and forming a ring; wall distinctly but rather finely perforate; aperture elongate on the middle part of the inner margin of the ventral side of the last-formed chamber.

Diameter, 0.60 millimeter.

Type specimens from the Eocene of Moctezuma River.

This species rather closely resembles that referred by Hantken to *Pulvinulina haidingeri* d'Orbigny. Hantken's specimens were from the European Eocene of the "*Clavulina-szaboi*" beds. D'Orbigny's original material was from the Oligocene of the Vienna Basin, and material I have from several localities from the Vienna Basin agrees with the types in having about six chambers in the last-formed whorl. But for the differences on the ventral side, these Mexican specimens are very similar to Hantken's figure.[1]

Pulvinulina crassata Cushman, n. sp.
Plate 7, Figure 4

Test small, plano-convex, the dorsal side nearly flat, ventral side strongly convex, last-formed coil with five or six chambers; periphery subacute; chambers inflated, especially on the ventral side; sutures distinct, slightly depressed

[1] *Mitth. Jahrb. kön. ung. Geol. Anstalt*, Vol. 4 (1875), Pl. 15, Fig. 10.

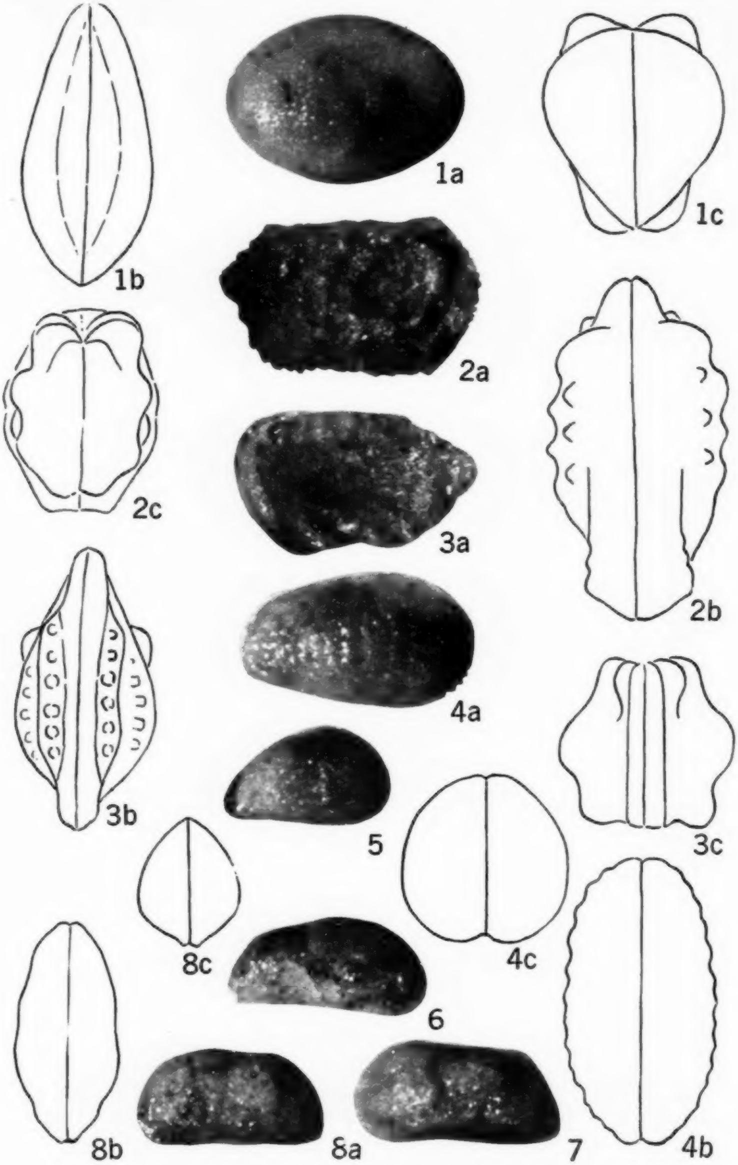


FIG. 1.—*Cytherella mexicana* Cushman, n. sp. *a*, side view, ×60; *b*, dorsal view, ×75; *c*, end view, ×75. FIG. 2.—*Cythereis mexicana* Cushman, n. sp. *a*, side view, ×60; *b*, dorsal view, ×75; *c*, end view, ×75. FIG. 3.—*Cythereis bassleri* Ulrich. *a*, side view, ×60; *b*, dorsal view, ×75; *c*, end view, ×75. FIG. 4.—*Cytheridea mülleri* (Münster). *a*, side view, ×60; *b*, dorsal view, ×75; *c*, end view, ×75. FIG. 5.—*Cytheridea mülleri* (Münster). Side view of smaller specimen, ×60. FIGS. 6, 7.—*Cythere oliveri* Cushman, n. sp. Side views, ×60. FIG. 8.—*Cythere oliveri* Cushman, n. sp. *a*, side view, ×60; *b*, dorsal view, ×75; *c*, end view, ×75.

on the dorsal side, strongly so on the ventral side; periphery and surface closely set with short spinose processes; aperture elongate, on the inner edge of the ventral face of the last-formed chamber.

Diameter, 0.45–0.55 millimeter.

Type specimens from Moctezuma River, Vera Cruz, Mexico, associated with *Operculina oliveri* Cushman, n. sp.

This species in its more flattened form has six chambers in the last-formed coil, and is sometimes at the edge very thin with almost a keel developed. It is associated with the following variety.

Pulvinulina crassata Cushman, n. sp., var. *densa* Cushman, n. var.

Test differing from the typical in the more rounded, compact form, the periphery rounded, usually only four chambers making up the last-formed coil.

Bulimina sp.?

Plate 7, Figure 9

There is a single specimen of a smooth species of *Bulimina* in the Eocene material from the Moctezuma, but without further specimens I hesitate to place it specifically.

Truncatulina sp.?

Plate 7, Figure 10

Occurring very rarely is a rounded, almost *Globigerina*-like species of *Truncatulina* with five chambers in the final coil.

OSTRACODA

Cytherella mexicana Cushman, n. sp.

Plate 8, Figures 1*a*–*c*

Carapace in side view oblong-ovate; dorsal margin slightly and evenly curved except for a slight concavity posterior to the middle; ventral margin broadly and evenly curved; anterior and posterior extremities nearly alike, evenly curved; surface of valve with slightly raised tuberosities near the central part of each end, the median area between slightly depressed; edge view of carapace compressed ovate, the ends nearly alike; end view, compressed ovate.

Length, 0.65 millimeter; height, 0.45 millimeter.

Type specimens from the Eocene of Moctezuma River.

The species is not at all common.

Cytheridea mülleri (Münster)

Plate 8, Figures 4*a*–*c*, 5

Carapace in side view ovate, dorsal and ventral margins nearly straight but divergent; anterior end broadly rounded, much higher than the somewhat more acuminate posterior end; both anterior and posterior ends slightly spinose at the periphery, general surface of the valve gently convex, the surface marked with a series of nearly vertical furrows extending entirely across the test, each furrow including a row of small punctations, larger toward the ventral border;

edge view broadly lanceolate, thickest slightly anterior to the middle; end view broadly elliptical.

Length, 0.65 millimeter; breadth, 0.35 millimeter.

In many ways the Mexican specimens resemble *C. perarcuata* Ulrich described from the Eocene of Maryland, but the ornamentation is not so restricted and the test not so high. It resembles *C. mülleri* more closely.

Cythereis bassleri Ulrich
Plate 8, Figures *3a–c*

Cythereis bassleri Ulrich, *Maryland Geological Survey, Eocene*, 1901, p. 120, Pl. 16, Figs. 19–21.

Carapace oblong, length 0.80 to 0.85 mm., widest and rounded anteriorly; the posterior edge more or less angular in the middle, straight or slightly sinuate above to the angular extremity of the hinge, and with two or three spines projecting from the slightly convex, lower half; edges with a thickened rounded rim, becoming obsolete near the center of the flattened ventral region; hinge line straight except at the antero-cardinal angle which is thickened and prominent; ventral outline slightly sinuate. Valves equal, with a rounded subcentral node, sometimes obscured by a network of small ridges, and a sharp ventral ridge rising gradually from its inception at the antero-ventral angle and ceasing abruptly at a point about one-fourth of the length of the valve from its posterior extremity. A less prominent ridge runs from the high end of the ventral ridge in a slightly oblique direction to the post-cardinal angle and then turns forward. The whole surface is covered with rather large pits arranged in more or less irregular curved series, the space between the rows, especially over the central portion of the valves being raised into thin and sometimes coalescing ridges.

Length of Mexican specimens, 0.70 millimeter; breadth, 0.40 millimeter.

The Mexican specimens are very close to the above species described by Ulrich from the Eocene (Aquia formation) of Maryland.

The posterior angle of our specimens is a little more pronounced, but the sum of the characters tallies very closely.

Cythereis mexicana Cushman, n. sp.
Plate 8, Figures *2a–c*

Carapace in side view generally oblong, widest anteriorly; dorsal margin straight; ventral margin straight except for a slight downward curve at the anterior end; anterior end broadly and evenly rounded; posterior end angular with a decided posterior end, the anterior end with a thickened ridge parallel to the periphery, with a deeply depressed area behind, posterior end thin, with a slight keel-like projection, remainder of the surface with larger bosses irregularly placed, the anterior and dorsal margins with short conical spinose projections.

Length, 0.75 millimeter; breadth, 0.45 millimeter.

Type specimens from the Eocene of Moctezuma River.

The species is a striking one, but not common.

Cythere oliveri Cushman, n. sp.
Plate 8, Figures 6–8

Carapace in side view generally oblong, widest anteriorly; dorsal and ventral margins nearly straight and nearly parallel, the dorsal margin slightly depressed in the middle, the ventral margin bending downward to begin the broad curve of the anterior end; posterior end obliquely truncate, forming a blunt angle with the ventral margin; the antero-ventral angle with a thin keel; surface at the anterior end with several furrows curved so as to appear nearly parallel with the periphery, the furrows including fine punctations, remainder of the surface with an irregular network of depressions and ridges making a strongly reticulate surface; greatest thickness of the carapace near the postero-ventral margin; edge view truncately ovate; end view oblong oval.

Length, 0.60 millimeter; breadth, 0.30 millimeter.

Type specimens from the Eocene of Moctezuma River.

This is the most common ostracod of the *Operculina* shales of this locality.

THE BLUE RIDGE SALT DOME, FORT BEND COUNTY, TEXAS[1]

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ABSTRACT

The Blue Ridge salt dome is a characteristic Gulf Coast salt dome and has a topographic mound, a stocklike salt core, a "lime" (gypsum) anhydrite cap, and steeply dipping beds on the flanks. The stratigraphic relations have been worked out by micropaleontologic studies. The beds penetrated by the drill are Pleistocene to Jackson in age. Modest, somewhat freaky production has been established. The gravity of the oil ranges from 18° to 46° Baumé, and on the average is around 28° Baumé. The production is from flank sands.

LOCATION

The Blue Ridge salt dome is in the eastern part of Fort Bend County, close to the Harris County line, Texas. It is 15 miles southwest of Houston, and 2 miles south of Missouri City. The Houston-Richmond pike runs through Missouri City, and dirt roads lead south from this highway to the field.

HISTORY

Blue Ridge comprises two low hills of about 20 feet elevation, lying some 3,500 feet apart on a northwest-southeast axis. On account of these two surface mounds, the Rio Bravo Oil Company drilled a test well (1)[2] in 1903, in the southwest corner of the Edward Drew survey, to a depth of 1,420 feet. Oil shows were encountered from 153 feet to the bottom; gypsum and lime at intervals from 156 to 790 feet, where lime and salt were found. At 820 feet, the main salt body was reached, and the well was abandoned in salt at 1,420 feet.

After the Rio Bravo test had proved the salt-dome character of the area, other operations were soon undertaken. Few ventured far from the first test. Beatty and House, of Houston, drilled the second well (2). It was 300 yards west of the Rio Bravo boring. Only insignificant shows of oil and gas were found, and the well was abandoned in salt and "lime" formation at 820 feet.

Next, Hager and Josey drilled a well (3) early in 1905, in Lot 4, Block E, Edward Drew survey. It was taken over by the Blue Ridge Oil and Develop-

[1] The writers are indebted to Don F. McIntosh, Gulf Production Company, for a large part of the information on the history and production of the field; to C. R. Carter for the drafting on the accompanying maps and sections.

[2] Numbers in parentheses following names of wells refer to index map and list.

ment Company, composed of Houston men, and completed at a depth of 900 feet, where it stopped in rock salt. Their No. 1 Blakeley (4), Lot 3, Block E of same survey, stopped in salt at 1,000 feet. This company drilled five wells in the southeast part of the Drew survey before applying for a receivership in 1906.

Early in 1907, the Valley Ridge Oil Company drilled a well in Lot 4, Block E, Drew survey, to 1,240 feet, and abandoned the test at that depth in salt. Showings of 17° Baumé gravity oil were reported from 700 feet. In the fall of 1907, the Daylight Oil Company drilled two wells, of which No. 1 was lost with casing twisted off, and No. 2 abandoned on account of water trouble at 1,132 feet. These were located 4,000 feet north of the wells in Lot 4, Block E, Drew survey. The Producers Oil Company took over the holdings of the Daylight Oil Company and in 1908 drilled Blakeley No. 1 (5) in the north part of the Drew survey to a depth of 1,100 feet; J. S. Stewart completed this well to 1,600 feet. Its only showing was a heavy asphaltum at 1,272 feet. J. S. Stewart *et al.*, in 1908, completed another well (6) at a depth of 1,300 feet near the center of Lot 8, Block C, Drew survey. It had a slight show at 1,200 feet. Both these tests were off the dome.

During the years 1909 to 1913, operations ceased at Blue Ridge. In the summer of 1914, the Blue Ridge Oil and Gas Company drilled two wells on the Blakeley land. Their No. 1 (7), Lot 6, Block C, Drew survey, was junked at 1,900 feet. The derrick was moved 55 feet north and, on Lot 7, a hole (8) sunk to 1,846 feet. Both these wells were to the north of the dome and had no oil shows of importance. Their third well (9), Lot 7, Block A, Robinson subdivision, was drilled to 700 feet; salt was reached at 640 feet.

In 1917, the Blue Ridge Development Company, including Esperson *et al.*, drilled No. 1 Adams (10) in the southwest corner of A. J. Adams subdivision, Thos. Habermaker survey, to 874 feet. Rock salt was reached at the shallow depth of 246 feet. In the same year, their No. 1 Robinson (11) was completed to a depth of 2,080 feet. This was southwest of the dome on the T. J. Ewing tract in the Hicks Shropshire survey. No showings were found.

In 1918, the Gulf Production Company entered the field. Their first well, No. 1 Robinson (12), was a dry hole, 3,328 feet deep. It was near the northeast corner of the Hicks Shropshire survey, north of the salt. Their next test, No. 1-C Blakeley (13), in the central eastern part of Lot 3, Block E, Drew survey, lost returns and was abandoned in salt water at 435 feet. In April, 1919, their third well, No. 2-C Blakeley (14), located 900 feet northeast of the second test, in Lot 3, Block F, Drew survey, came in flowing 1,200 barrels per day by heads, at 2,700 feet. The gravity of this oil was 29.3° Baumé. It distilled considerable kerosene, but little gasoline. This was the first commercial well in the field. Although it was considered rather a freak well, it drew the attention of large producers to the field and brought on a more systematic drilling campaign. As much as $700 an acre was paid for acreage more than 1,000 feet from the well. By the end of the year, eight of the larger operators were engaged in active development, among them the Gulf Production Company, The Texas Company,

Sinclair Oil Company, Republic Production Company, West Production Company, and R. C. Duff.

In 1919, the Gulf Production Company completed Luscher Nos. 1 (14) and 2 (15) as small pumpers. During 1920, development was active on the eastern side of the dome, and continued to about the fall of 1921. Some drilling continued during 1922 and 1923. On the west side of the dome, development became very active in the late fall of 1920 when The Texas Company completed No. 1 Robinson (40) in the latter part of October, for 5,000 barrels of fluid, 50 per cent water. The intense drilling continued in 1921. The main development was on 1-acre lots of blocks 2, 3, 13, and 14, Robinson subdivision, Shropshire survey. As high as $10,000 for 1 acre was paid. In general, the sands on the west side proved freaky; they were thin and pinched out sharply. Interest rapidly slackened. In June, 1923, The Texas Company revived it by bringing in their No. 10 Robinson (94), farther northwest, for 3,000 barrels per day. By December, this well was pumping 150 barrels per day.

At the present time, three wells are being drilled at Blue Ridge.

PHYSIOGRAPHY

The Blue Ridge mound covers approximately 1,000 acres, and rises to a height of about 20 feet above the surrounding country. Its shape is shown on the accompanying topographic map, which was made by the Roxana Petroleum Company (Fig. 1). Its axis strikes northwest and southeast. There are two flat hills on the dome, about 3,500 feet apart, with an intervening low area. It is interesting to note that the depression on the surface overlies the highest part of the salt core. This topographic low was probably caused by the leaching out of the top of the salt by surface waters.

GEOLOGY

Blue Ridge is a typical Gulf Coast salt dome, composed of a salt core intruded through the surrounding shales and sands and surmounted by cap rock.

The shape of the salt core is elliptical, as indicated by the wells which have been drilled into salt. Such wells show the salt to extend approximately 1.5 miles along the northwest-southeast axis, and 1 mile at right angles to this axis. As can be seen from the cross-sections, the depth to the salt varies from 143 feet on top of the dome to over 3,500 feet on the flanks. The top of the salt core slopes gently, but the sides dip sharply. The three sections across the dome, shown in Figure 2, serve to bring out the shape of the salt core.

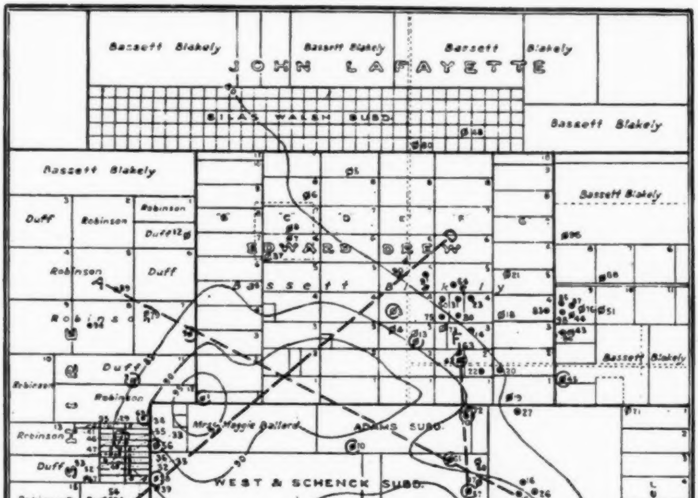

FIG. 1.—Topographic map of the Blue Ridge salt dome

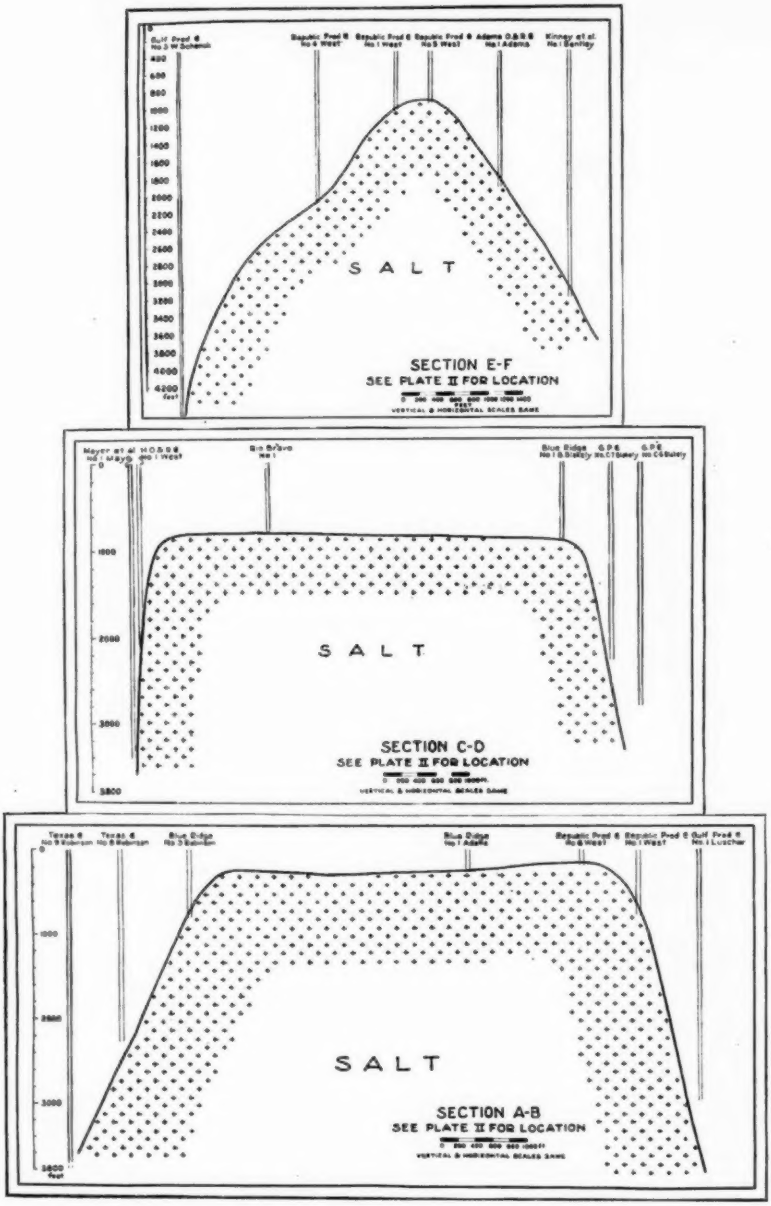

FIG. 2.—Cross-sections of the salt core. For the position of the sections see Figure 1

The outline of the salt in these sections is more or less hypothetical, inasmuch as there are not enough wells drilled on the top of the dome to define its shape. The top of the salt along the northwest and southeast axis, Section *A-B*, is relatively broad and flat. This is also true along the northeast-southwest axis, Section *C-D*. At the southeast end of the field, Section *E-F*, in a north-and-south direction, shows the top of the salt to be narrow and rounded.

The cap rock is not found in wells drilled away from the salt core. It is best developed on the dome. The cap consists of "lime" and gypsum with salt interbedded, and pyrites; in some wells it had shows of oil and sulphur. In one well, the Adams Oil Co. No. 1 Adams (70), it produced some oil. In Republic Production Co.'s No. 6 West (61) there were 87 feet of salt and gypsum; in the No. 5 West (60), 179 feet of salty shale, "lime," and "gyp" rock; in the No. 2 West (57), only 60 feet of soft gypsum; and in No. 1 West (17), 109 feet of gypsum and salt. In the Rio Bravo Oil Co. No. 1, there were 450 feet of "lime," pyrites, gypsum, and salt interbedded. These figures indicate that the cap rock is thicker toward the top of the dome, wedges out toward the edges, and finally disappears. On the higher parts of the dome, part of it has possibly been eroded.

On the east side of the salt, the oil sands dip away from the core at angles of 35° to 45°, as measured between the Gulf Production Co. Bassett Blakeley No. 2-C (14) and the Oil Production Co. No. 1 Lee-Bashara (98). On the west side, the dip seems to be greater, especially close to the salt. Paleontological examination of cuttings from wells, discussed under "Stratigraphy," indicates that on the west side of the dome this sharp dip diminishes within a short distance away from the salt. The dip on the base of the Fleming between The Texas Co. Robinson No. 9 (89) and No. 10 (94) is 380 feet in a distance of 760 feet, or at the rate of 27° to the southwest; from Robinson No. 10 to the Mutual Oil Co. No 1 Weems (97), the base of the Fleming dips 364 feet in a distance of 1,300 feet, or at the rate of 16°.

STRATIGRAPHY

The data in regard to stratigraphy of the Blue Ridge field were secured through courtesy of the paleontological departments of The

Texas Co. and the Humble Oil and Refining Co., and apply chiefly to the area west of the salt.

The surface formations at Blue Ridge are Pleistocene in age. Except on top of the salt core, the thickness of these beds is fairly uniform. They consist of 500 feet of clays, sands, and gravels, the upper part of which belongs to the Beaumont or Coast clays, the lower part to the Lafayette or Lissie gravels.

The top of the Fleming, which embraces the Pliocene-Miocene formations, is about 500 feet below the surface in Robinson No. 10, the base at 3,800 feet. Aragonitic prisms and re-worked Foraminifera are typical of this formation. The upper 1,000 feet of the Fleming are mainly gumbo, sand, and bowlders; the middle and lower parts, from 1,400 to 3,760 feet, contain much lime, with shales and bowlders. The oil sand at 3,900 feet is in the top of the Oligocene. In No. 9 Robinson (89), the base of the Fleming is placed at 3,470 feet.

The Oligocene in No. 9 Robinson extends from 3,470 feet to the bottom of the well at 3,892 feet. The Oligocene consists here of gray sand and shale, and some pyrite and glauconite. At 3,867 feet, anhydrite was found, possibly in the cap. The production is from the upper part of the Oligocene. In the Mutual Oil Co. No. 1 Weems (97), the Fleming-Oligocene contact was at 4,229 feet, and the well is still in Oligocene at 4,450 feet, the present depth of the well. Samples from that depth show fine gray sand. In The Texas Co. No. 1 Robinson (40), which is closer to the salt than wells previously mentioned, the base of the Oligocene is at 3,410 feet, and consists of gray marly clay. A sample at 3,662 feet was determined as being from low in the Jackson formation.

A sample from the Humble Oil and Refining Co. No. 1 Damon Mound (32), at 3,507 feet, was determined as Miocene; Oligocene extended from 3,649 feet to the bottom of the hole. The same company's Dew No. 1 (33) was still in Miocene at 3,238 feet, and their West No. 2 (74) was in the Miocene, or the lower part of the Fleming, from 1,730 to 2,862 feet. Scattered samples from 2,862 to 2,866 feet in this well showed Oligocene fossils; and one sample from 3,051 to 3,246 was of Jackson or upper Eocene age. The Oil Issues Co. No. 1 Booth (54) had Oligocene at 3,897 to 3,907 feet.

On the east side of the dome, the Kirby Petroleum Co. No. 2 Lee-Blakeley (85) had Oligocene at 3,741 feet, and the Sinclair Oil

Co. No. 1 Lee-Bashara (44) was in Oligocene at 3,655 feet. In neither case did the sample indicate the top of the Oligocene.

On the west side of the field, the oil is coming from sands in the upper part of the Oligocene. This may hold true for the eastern part of the field, but sufficient paleontological work has not yet been done in that area.

OIL AND GAS

The field was first tested on account of the mound. Gas or oil seeps were not found at Blue Ridge.

The character of the oil at Blue Ridge varies. On the western flank of the dome, the gravity is from 28.5° to 31° Baumé; in the northeast area, from 18.4° to46° Baumé. The best wells there produce oil of 24.4° to 29° Baumé gravity. The oils of extremely high or low gravities are found only in freak wells. In the southeastern area, the gravity of the oil ranges from 22.4° to 23.5° Baumé. This is a typical Gulf Coast crude. The wells there on the average are the best in the whole field.

In the western area, the oil for the most part is found in sharply dipping beds close to the salt. The wells usually came in flowing from several hundred to several thousand barrels per day. Within twenty-four hours, or at most a few days, the wells generally settled to steady flowing wells or pumpers of about 100 to 150 barrels per day, continued to produce from several months to a year, and then sanded up and were abandoned. A production curve for the Humble Oil and Refining Co. No. 1 Damon Mound (32) is shown in Figure 3.

In the northeastern part of the field the production of the 24° to 29° Baumé gravity wells generally came in for a few hundred to several thousand barrels per day. Some of them flowed several hundred barrels per day for months and then made good pumpers of 60 to 90 barrels or less per day. Figure 3 includes a production curve of the Gulf Production Co. No. 2-C Blakeley (14).

In this section of the field several wells have also come in making high-gravity oil; also one of low gravity. The Gulf Production Co. No. 4 Luscher (27) produced 39° Baumé gravity oil. This well came in flowing 300 barrels per day. For the first month, the well averaged 166 barrels per day. It decreased gradually until at the end of the first year it was producing about 8 barrels per day. At the end of the second year it was still producing from 2 to 2½ barrels per day. The

Sinclair Oil Co. Davidson No. 2 (86) came in flowing 300 barrels per day of 42° Baumé gravity oil at 3,226 feet. Three and a half months later, it was producing 120 barrels daily; a year and nine months later, it was still making 30 barrels daily. The Texas Co. Fee No. 2 (75) was

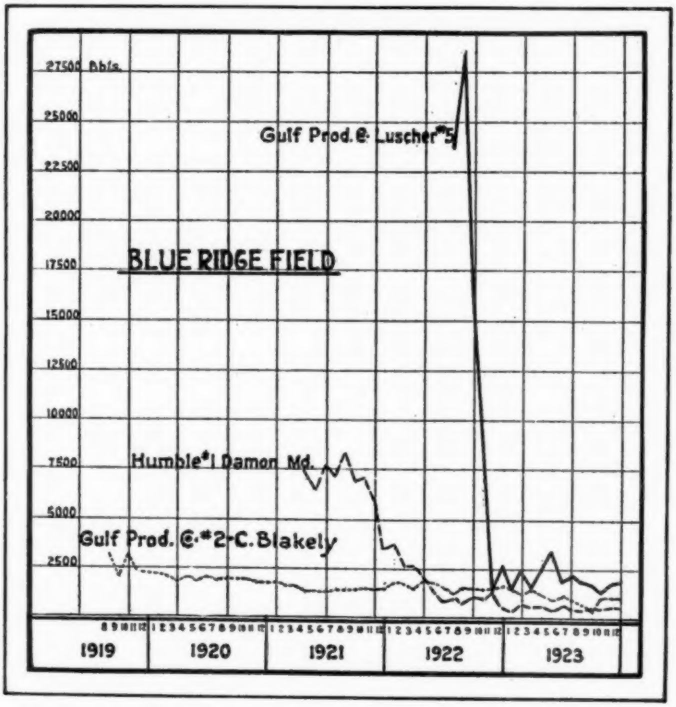

FIG. 3.—Curves of monthly production for Gulf Production Co. Luscher No. 5 and Blakeley No. 2-C and for Humble Oil and Refining Co. Damon Mound No. 1.

a small pumper of 18.4° Baumé gravity oil. It came in for 30 barrels and went up to 80 barrels per day; at the end of six months it was pumping 10 barrels per day. It was probably in a sandy lens fairly close to the salt.

The production in the northeast area is from hard sand and sandy shale, away from the flank of the salt. In some logs, only sandy shale is shown. The pay ranges in thickness from 40 feet to over 100

feet; the sand ranges from 10 to 40 feet, or over, and the rest of the pay is sandy shale.

In the southeastern area, the oil is found in beds close to the salt. As already stated, it is typical Gulf Coast crude, and the wells are the best in the field. To date only a few wells have been drilled there. Of these only three are producing at present: the Gulf Production Co. Luscher No. 5 (65) and No. 6 (92), and West-Shenck No. 3 (84). The production curve of Luscher No. 5, which is typical of this area, is shown in Figure 3.

No paying production has been found in the cap rock. The Adams Oil Co. No. 1 Adams (70) flowed 100 barrels for one day of 32° Baumé gravity oil from the top of the cap at 848 feet. It was not possible to pump this well, as there was no fluid in the hole. After being drilled 3 feet deeper, the well pumped 10 barrels for one day and then averaged about 2 barrels per day for a week, when it stopped pumping. Although shows were had in the cap rock, sulphur was not found in commercial quantity.

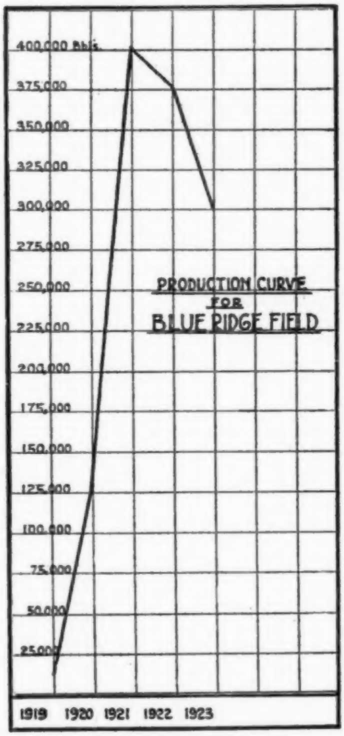

FIG. 4.—Curve of yearly production for the whole field.

The production curve for the entire field up to January, 1924, is given in Figure 4.

The Gulf Production Co. at present runs most of the oil from the field through its 6-inch line. The oil is refined at Port Arthur. The Sinclair Co. has an 8-inch line from the field $1\frac{1}{4}$ miles eastward to a loading-rack at Almeda, on the I. & G. N. Railroad. The Texas Co. has a loading-rack on the Southern Pacific Railroad.

TABLE I

Temperature (F.)	Percentage	Gravity Baumé	Remarks
Blakeley No. 1, Blue Ridge Production Co. (Kavanaugh & West)			
146°–248°	10	58.5°	
248 –275	10	54.4	Crude, 44.5° Baumé
275 –302	10	52.0	Over-point, 146° F.
302 –319	10	49.9	Gravity of total distillate (79 per cent), 48.4° Baumé
319 –364	10	47.8	
364 –413	10	45.2	Distillation loss, 1 per cent
413 –461	10	41.6	
461°–500°	9	37.7	
Residue	20	30.6	
Blakeley No. 2-C, Gulf Production Co.			
167°–308°	10	59.5°	Crude, 29.3° Baumé
308 –369	10	46.6	Over-point, 167° F.
369 –462	10	36.4	Gravity of total distillate (37.5 per cent), 43.3° Baumé
462°–500°	7.5	30.5	
Residue	61.2	21.6°	Distillation loss, 1.3 per cent
Pilant No. 1, Gulf Production Co.			
164°–278°	10	53.4°	Crude, 30.4° Baumé
278 –325	10	46.1	Over-point, 164° F.
325 –384	10	39.6	Gravity of total distillate (52 per cent), 38.9° Baumé
384 –443	10	33.3	
443 –495	10	29.6	Distillation loss, 1 per cent
495°–500°	2	....	
Residue	47	20.3°	
Luscher No. 5, Gulf Production Co.			
254°–450°	10	41.0°	Crude, 23.7° Baumé
450 –515	10	32.5	Over-point, 254° F.
515°–527°	3	29.7	Gravity of total distillate (23 per cent), 35.6° Baumé
Residue	76.83	20.9°	
			Distillation loss, 0.17 per cent

Analyses of the oil from Blue Ridge, made by E. T. Gregg and F. M. Seibert of the Gulf Pipe Line Laboratory, Houston, Texas, are given in Table I. The first is of an oil from the western side of the dome, the second of a typical oil from the northeast section, the third of a high-gravity oil from the same area; and the last is of a typical oil from the southeast side of the dome.

TABULAR LIST OF WELLS

Table II gives a list of the wells drilled in the field, showing owner, farm, total depth, date of completion, initial production, and

TABLE II

Map No.	Company	Well	Total Depth (Feet)	Date Completed	Initial Production (Barrels)*	Present Production (Barrels Daily)
1	Rio Bravo Oil Co.	No. 1	1,420	....	S at 820 ft.	....
2	Beatty & House	No. 1	820	....	....	....
3	Blue Ridge O. & D. Co.	....	900	....	S at 900 ft.	....
4	Blue Ridge O. & D. Co.	No. 1 Blakeley	1,000	....	S at 1,000 ft.	....
5	Producers Oil Co.	No. 1 Blakeley	1,600	....	....	....
6	J. S. Stewart *et al.*	....	1,300	....	....	....
7	Blue Ridge O. & G. Co.	No. 1 Blakeley	1,900	....	....	....
8	Blue Ridge O. & G. Co.	No. 2 Blakeley	1,846	....	....	....
9	Blue Ridge O. & G. Co.	No. 3 Robinson	700	....	....	....
10	Blue Ridge O. & G. Co.	No. 1 Adams	874	....	....	....
11	Blue Ridge O. & G. Co.	No. 1 Robinson	2,080	....	....	....
12	Gulf Production Co.	No. 1 Robinson	3,328	....	....	....
13	Gulf Production Co.	No. 1-C Blakeley	435	....	....	....
14	Gulf Production Co.	No. 2-C Blakeley	2,700	4-4-19	1,200	43
15	Gulf Production Co.	No. 1 Luscher	2,720	....	....	....
16	Gulf Production Co.	No. 2 Luscher	2,696	6-13-20	P 25	5
17	Republic Production Co.	No. 1 West	2,000	....	S at 621	....
18	Gulf Production Co.	No. 1-B Blakeley	2,913	....	SW	....
19	Gulf Production Co.	No. 2-B Blakeley	2,817	5-24-20	P 75	....
20	Gulf Production Co.	No. 3-B Blakeley	2,974	1-29-21	250	16
21	Gulf Production Co.	No. 4-B Blakeley	4,155	....	....	....
22	Gulf Production Co.	No. 3-C Blakeley	2,750	10-14-20	1,500	....
23	Gulf Production Co.	No. 4-C Blakeley	2,696	4-12-21	1,000	....
24	Gulf Production Co.	No. 1 Goodman	2,673	....	....	....
25	Gulf Production Co.	No. 2 Goodman	2,718	....	....	....
26	Gulf Production Co.	No. 3 Luscher	2,938	2-5-21	P 40	5
27	Gulf Production Co.	No. 4 Luscher	2,645	1-3-21	300	4
28	Gulf Production Co.	No. 1 West-Shenck	3,481	....	SW	....
29	Gulf Production Co.	No. 1 Pilant	3,633	1-26-21	500	....
30	Gulf Production Co.	No. 2 Blakeley	2,538	3-13-21	150	33
31	Gulf Production Co.	No. 1 Blakeley	2,695	10-20-20	3,500	....
32	Humble Oil & Rfg. Co.	No. 1 Damon Mound	3,947	3-9-21	276	15
33	Humble Oil & Rfg. Co.	No. 1 Dew Bros.	3,301	2-15-21	600	....
34	Humble Oil & Rfg. Co.	No. 2 Dew Bros.	3,200	3-9-21	1,912	....
35	Humble Oil & Rfg. Co.	No. 1 Myers	3,532	....	....	....
36	Humble Oil & Rfg. Co.	No. 1 Pearson	2,967	1-12-21	300	....
37	Humble Oil & Rfg. Co.	No. 1 Blakeley	4,157	....	....	....
38	Humble Oil & Rfg. Co.	No. 1 West	2,315	....	S at 2,142 ft.	....
39	Mayer *et al.*	No. 1 Mayo	3,479	....	....	....
40	The Texas Co.	No. 1 Robinson	4,112	10-24-20	5,000 ½SW	....
41	Kavanaugh Pet. Co.	No. 1 Isbell	880	....	....	....
42	Kinney *et al.*	No. 1 Bentley	2,779	....	....	....
43	Sinclair Oil Co.	No. 1 Davidson	3,350	....	....	....
44	Sinclair Oil Co.	No. 1 Lee-Bashara	3,832	....	....	....
45	Blue Ridge Prod. Co.	No. 1 Blakeley	3,924	....	S at 1,000 ft.	....
46	Crown Oil & Rfg. Co.	No. 1 Johnson	3,531	....	S at 3,333 ft.	....
47	Crown Oil & Rfg. Co.	No. 1 Ransom	3,700	....	....	....
48	Deep Blue Ridge Oil Co.	No. 1 Blakeley	3,235	....	....	....
49	Invincible Oil Co.	No. 1 Esperson	3,960	6-3-21	500	4
50	Bennett, Jones, McClanahan	No. 1 Texas Co.	2,894	1-21-21	500	....
51	R. C. Duff	No. 1 Soderberg	4,445	....	....	....
52	Mutual Oil Co.	No. 1 Booth	3,952	6-..-21	2,000	28
53	Oil Issues Co.	No. 2 Booth	3,517	....	....	....
54	Oil Issues Co.	No. 1 Booth	868	....	....	....
55	Republic Production Co.	No. 1 Booth	3,300	....	S at 3,300 ft.	....
56	Republic Production Co.	No. 1 Callahan	3,200	....	S at 2,402 ft.	....
57	Republic Production Co.	No. 2 West	505	....	S at 450 ft.	....
58	Republic Production Co.	No. 3 West	2,000	....	S at 2,000 ft.	....
59	Republic Production Co.	No. 4 West	1,700	....	S at 1,700 ft.	....
60	Republic Production Co.	No. 5 West	705	....	S at 560 ft.	....
61	Republic Production Co.	No. 6 West	230	....	S at 143 ft.	....
62	Republic Production Co.	No. 7 West	2,755	....	....	....
63	Taylor Oil Co.	No. 1 Blakeley	2,116	....	....	....
64	Gulf Production Co.	No. 5-C Blakeley	3,038	5-20-21	300	....
65	Gulf Production Co.	No. 5 Luscher	4,009	7-12-22	1,500	68

* The symbols in this column have respectively the following meanings: S = show of oil, SW = salt water, P = pumped. If the initial production is given without the P, the well came in flowing.

TABLE II—*Continued*

Map No.	Company	Farm	Total Depth (Feet)	Date Completed	Initial Production (Barrels)*	Present Production (Barrels Daily)
66	Gulf Production Co.	No. 2 West-Shenck	3,914	9-19-21	P 40	....
67	The Texas Co.	No. 7 Robinson	4,593	....	....	....
68	Amerada Petroleum Co.	No. 1 West-Shenck	3,505	....	....	....
69	The Texas Co.	No. 3 Robinson	639	....	S at 639 ft.	....
70	Adams Oil & Dev. Co.	No. 1 Adams	1,444	....	S at 1,444 ft.	....
71	West Production Co.	No. 1 Luscher	3,340	....	....	....
72	Adams Oil & Dev. Co.	No. 2 Adams	767	....	....	....
73	Baker Oil Co.	No. 1 Bentley	1,584	....	....	....
74	Humble Oil & Rfg. Co.	No. 2 West	3,483	....	S at 3,406 ft.	....
75	Jones, McClanahan	No. 2 Texas Co.	1,672	3-2-21	P 30	....
76	Kirby Petroleum Co.	No. 1 Bashara	4,413	....	....	....
77	Sinclair Oil Co.	No. 1 West-Shenck	3,124	....	....	....
78	Turnbow Petroleum Co.	No. 1 Christian	4,336	....	SW	....
79	The Texas Co.	No. 8 Robinson	2,243	....	....	....
80	Blue Ridge Oil Co.	No. 1 Blakeley	2,638	....	....	....
81	Neil Esperson	No. 2 Ewing	3,904	....	....	....
82	Neil Esperson	No. 1 Ewing	5,278	....	....	....
83	Gulf Production Co.	No. 5-B Blakeley	3,935	4-30-22	50	....
84	Gulf Production Co.	No. 3 West-Shenck	3,979	10-14-22	2,600	177
85	Kirby Petroleum Co.	No. 2 Lee	3,981	5-14-22	2,500	....
86	Sinclair Oil Co.	No. 2 Davidson	4,106	3-31-22	300	20
87	Sinclair Oil Co.	No. 2 Bashara	3,996	12-7-22	140	....
88	Sinclair Oil Co.	No. 1 Lee-Smith	4,136	....	....	....
89	The Texas Co.	No. 9 Robinson	3,892	....	S at 3,729 ft.	....
90	Gulf Production Co.	No. 7-C Blakeley	2,278	4-24-23	250	5
91	Gulf Production Co.	No. 6-C Blakeley	2,771	3-2-23	200	....
92	Gulf Production Co.	No. 6 Luscher	3,815	5-22-23	2,000	124
93	Gulf Production Co.	No. 4 West-Shenck	3,622	....	S at 3,413 ft.	....
94	The Texas Co.	No. 10 Robinson	3,900	6-13-23	3,000	76
95	Blue Ridge Prod. Co.	No. 1 Robinson	4,004	....	....	....
96	The Texas Co.	No. 1 Blakeley	3,619	....	....	....
97	Mutual Oil Co.	No. 1 Weems	4,450	Drilling	....	....
98	Oil Production Co.	No. 1 Lee-Bashara	4,029	1-12-22	4,000	....

*The symbols in this column have respectively the following meanings: S=show of oil, SW=salt water, P=pumped. If the initial production is given without the P, the well came in flowing.

present production. The index-map numbers are in general chronological order with reference to the commencement of wells, but no attempt was made to get an exact chronological sequence.

THE PRODUCTION OF OIL IN INDIANA

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ABSTRACT

The chief oil production of Indiana during the earlier years of development came from the Trenton limestone of the Ordovician in the east central part of the state, the highest annual state yield, 13,000,000 barrels in 1904, marking the climax of this production. In later years new fields in the southwestern part of the state have been discovered, the oil coming chiefly from the Chester series, Upper Mississippian, and the Pottsville and Allegheny series of the Pennsylvanian. At present approximately two-thirds of the oil production of Indiana comes from this district. Subsurface study shows that the oil- and gas-producing structures are generally asymmetrical anticlines with small superimposed domes. There are untested areas and horizons that offer possibilities of new production.

INTRODUCTION

The production of oil and gas in Indiana began about 1885, when the Trenton limestone of the east central part of the state was found to produce oil and gas. At that time natural gas was of more importance than oil, and little effort was made to develop oil-producing territories. Since then, however, the situation has been reversed, as at the present time only a small quantity of gas is being produced in the state. Oil production from the Trenton reached its climax in 1904, when the production for the state reached a mark of 13,000,000 barrels, 11,000,000 barrels of which came from this horizon. In 1904 the Princeton pool of Gibson County was discovered, and then began the development of productive areas in the southwestern part of the state. Since then more than a dozen small pools have been found, and at the present time more than three-fourths of all the oil produced in the state comes from the southwestern district. The annual production for the state the past several years has stood around the million-barrel mark.

[1] This paper is based on work done by the author while a member of the Geological Survey of Indiana. For much of the general geological information and for a portion of the data on the geological map, credit is due to many members of Indiana University, and to the various state geologists and their surveys, especially the present state geologist, W. N. Logan.

At present, the southwestern district receives more attention from operators than the Trenton area, although there is considerable drilling in the old field. Recent strikes in adjacent counties in Ohio have stimulated new drilling in Jay County, with the result that two new pools have been found.

LOCATION OF PRODUCING DISTRICTS

The producing territory in the east central part of the state, a part of the Lima-Indiana field, also known as the Trenton rock area, embraces the following counties: Adams, Wells, Grant, Howard, Tipton, Madison, Hamilton, Hancock, Marion, Blackford, Jay, Delaware, Randolph, Henry, Rush, and Decatur. Gas and oil have been produced in all of these counties. The most important oil-producing counties at the present time are Jay and Delaware. Production is found in the Trenton limestone, which is from 800 to 1,200 feet deep. Individual gas fields sometimes cover many square miles, although they are irregularly drilled. Most of the wells were drilled by local individuals, syndicates, and companies, with the result that the records, logs, and even the locations have been lost or destroyed. There are many oil wells in this old field which have been producing oil for thirty years. The high quality of the oil, its low cost of production, and the long life of the wells make producing properties here very attractive.

Production in the southwestern part of the state is found in a number of sands at depths varying from 600 to 1,500 feet. The most important producing counties are Gibson, Pike, and Sullivan, although some oil has been found in Dubois, Knox, Daviess, Martin, Clay, and Vigo. The southwestern part of the state is strictly an oil-producing area, very little gas in marketable quantities having been found. Production statistics and records have been kept for the larger part of the area and are available from the producing companies and the state geological survey. Oil production in this part of the state in most respects is similar to that of southeastern Illinois.

Shallow production is found in a few other counties in Indiana, namely, Harrison, Jasper, and Noble. In Harrison County is found a small gas field, and in the other two oil is produced.

GEOLOGY

The regional geology of the state is relatively simple, although in some cases the interpretation of local geologic features is rather complex (Fig. 1). The state is roughly divided from the northwest corner to the southeast corner by the Cincinnati geanticline. The rocks exposed on the crest of this anticline are mostly of Silurian age. As the rocks dip northeastward away from the anticline toward the center of the Michigan coal basin, successive younger rocks outcrop. The same is true southwestward from the anticline, the Devonian, Mississippian, and Pennsylvanian rocks being found in belts parallel to the crest of the anticline, and dipping an average of 25 feet per mile toward the center of the Indiana-Illinois coal basin. The northern half of the state, especially that portion covered by the east central fields, is largely covered with glacial drift from a few feet up to 300 feet in thickness. This prohibits the usual methods of geological investigation, and all that is known of the structure of the producing Trenton area has been determined by subsurface studies. A part of the southwestern district of the state is also covered with glacial drift, but it is usually so thin and scattered that local structural conditions may be determined by use of the surface rocks.

In the area of Trenton production, the rocks lying immediately below the glacial drift belong to the Silurian system, and in some places the Devonian. Because of erosion before the deposition of the glacial drift, the thickness of the Silurian rocks is irregular, 600 to 800 feet being present. Nearly all the Silurian present is of Niagaran age and is largely composed of dolomitic limestone. In a few places gas has been found in the Niagaran rocks. Oil and gas have been found in the Trenton limestone as much as 300 feet below its top. Production is usually found in the upper 50 feet of the formation and is generally known as the "first" pay by the drillers. Deeper pays, when found a considerable distance below the top, are commonly known as the "second" pay, although they do not belong to a definite stratigraphic horizon. The Trenton is an irregularly dolomitic limestone, dolomitization being accountable for the porosity of the rock and the accumulation of oil.

Subsurface study has shown that the type of structure from

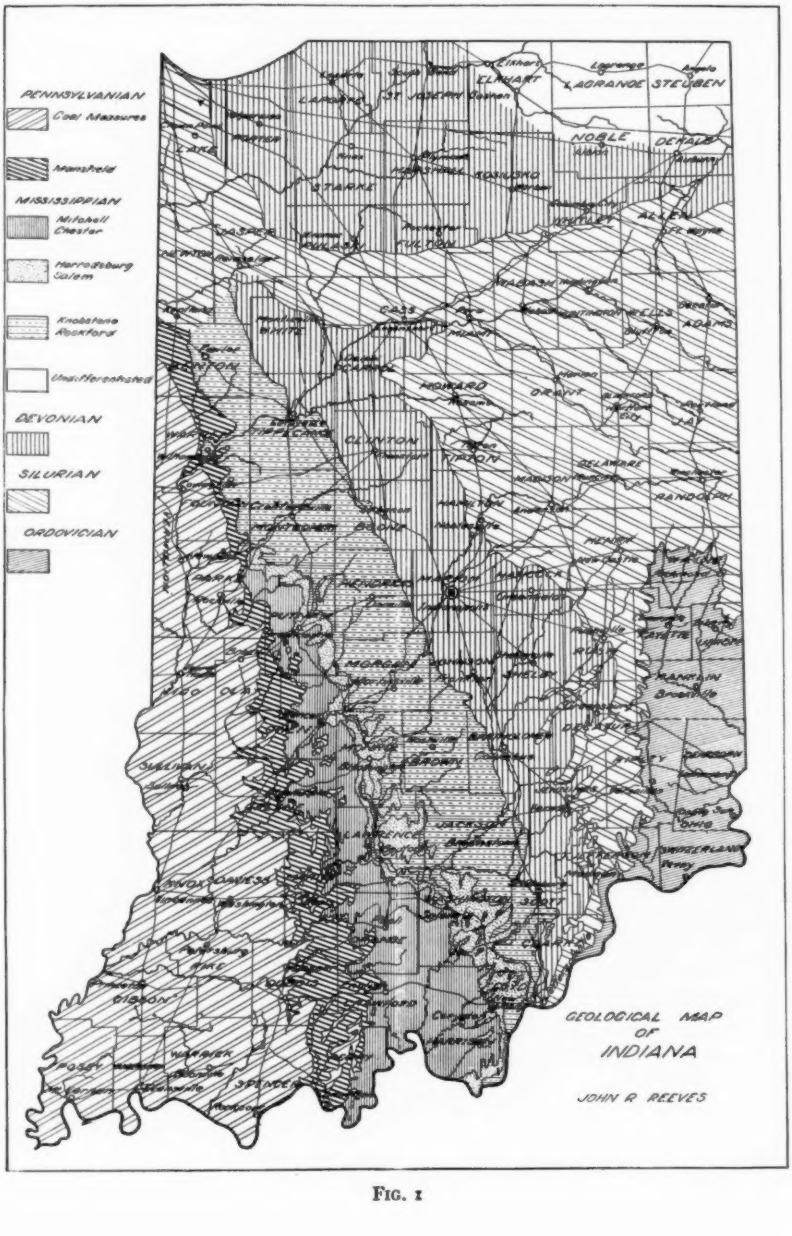
PENNSYLVANIAN
Coal Measures
Mansfield
MISSISSIPPIAN
Mitchell
Chester
Harrodsburg
Salem
Knobstone
Rockford
Undifferentiated
DEVONIAN
SILURIAN
ORDOVICIAN
GEOLOGICAL MAP
OF
INDIANA
JOHN R REEVES

FIG. 1

TABLE I

Indiana Geological Time Scale
(After E. R. Cumings)

Pennsylvanian	Post-Allegheny	Merom	Merom sandstone
		Shelburn	Sommerville limestone
			Coal VIII
	Allegheny	Petersburg	Coal VII (Millersburg)
			Coal VI
			Coal V*a*
			Coal V (Petersburg)
			Coal IV*a*
		Staunton	Coal IV (Linton)
			Coal III*a*
			Coal III (Seelyville)
	Pottsville	Brazil	Coal II (Upper Minshall)
			Lower Minshall coal
			Upper Block coal
			Lower Block coal
		Mansfield	Coal I (Cannelton)
Mississippian	Chesterian	Randolph	Buffalo Wallow sandstone
			Siberia limestone
			Tar Springs sandstone
		Stephensport	Glendean limestone
			Hardinsburg sandstone
			Golconda limestone
			Indian Springs shale
			Cypress sandstone
		West Baden	Beech Creek limestone
			Elwren sandstone
			Reelsville limestone
			Brandy Run sandstone
			Beaver Bend limestone
			Mooretown sandstone
			Paoli limestone
	Meramecan	St. Genevieve	Fredonia limestone
		St. Louis	St. Louis limestone
		Salem	Salem limestone
		Warsaw	Harrodsburg limestone
	Osagean	Keokuk	Riverside sandstone (Holtsclaw)
			Rosewood shale
			Kenwood sandstone and shale
		Burlington	New Providence shale
	Kinderhookian		Rockford limestone
Devonian	Senecan	Portage-Genesee	New Albany shale
	Erian	Hamilton	Beechwood limestone
			Silver Creek limestone
		Onondaga	Jeffersonville limestone
	Oriskanian	Schoharie	Pendleton sandstone
Silurian	Cayugan	Bertie	Kokomo limestone
	Niagaran	Guelph	Huntington limestone
		Lockport	Noblesville dolomite
			Louisville limestone
			Waldron shale
			Laurel limestone and shale
		Rochester	Osgood limestone
	Medinian	Cataract	Brassfield lime and shale

TABLE I—*Continued*

Silurian (*Cont.*)	Medinian (*Cont.*)	Richmond	Elkhorn lime and shale
			Whitewater lime and shale
			Saluda limestone
			Liberty lime and shale
			Waynesville lime and shale
Ordovician	Cincinnatian	Maysville	Arnheim lime and shale
			Mount Auburn lime and shale
			Corryville lime and shale
			Belleview lime and shale
			Fairmount lime and shale
			Mount Hope lime and shale
		Eden	McMicken lime and shale
			Southgate lime and shale
			Economy lime and shale
	Mohawkian	Trenton	Cynthiana limestone

which oil and gas is produced is usually of the asymmetrical anticline type, with small superimposed domes. Little work has been done in determining the subsurface structure of this region, and many interesting facts not now known will undoubtedly be brought to light by detailed studies. At certain points on and near the crest of the Cincinnati anticline, on which the Trenton field is located, unusual quaquaversal folds are known to exist, concerning which little is known. Three of these prominent folds are found near Wabash, Huntington, and Kentland. In these localities the glacial drift is thin or absent and parts of the structure may be seen, although outcrops are not sufficiently abundant to permit detailed surface mapping. Dips as great as 20° are found on the flanks of these folds, and the rocks in their centers are considerably older than those flanking the sides. There are evidences that other folds occur on the main anticline, and it is quite probable that they exist in the oil- and gas-producing territories, although their relation to production is unknown.

Production in the southwestern part of the state is found principally in the Chester series, the highest series of the Mississippian, and in the Pottsville and Allegheny series of the Pennsylvanian. The Chester series is composed of a number of alternating formations of sandstone, limestone, and shale, the shale and sandstone predominating. There are four or five limestone members which make excellent horizon-markers although extreme care must be used in their identification. The sandstones are not very persistent in thickness and commonly thin or pinch out. The most prominent

sandstone member of the series is the Cypress, which in places contains oil, but in most places water. From 100 to 200 feet of the Chester is present in the southwestern oil fields, though it may be considerably more than this locally. Variation in thickness is due to the Pennsylvanian-Mississippian unconformity, which, in conjunction with poorly kept logs, makes it difficult to determine the top of the Mississippian rocks in wells. One feature which distinguishes the Chester from the Pottsville is the presence of maroon and green shales in the former.

The Pennsylvanian rocks range in thickness up to 1,200 feet at the west state line. The Pottsville and Allegheny series are present and possibly a part of the Conemaugh, the last not being definitely known. The Pennsylvanian is composed for the most part of shale and sandy shale, some sandstone, a number of persistent coal beds, and a few thin limestones. Oil is found in the Pottsville in at least two different horizons, the lower just below Coal I, and the second between the Upper and Lower Block coals. Oil has been found in the Allegheny below Coal III. There are possibly other producing "stray" sands in the Mansfield formation of the Pottsville.

For the determination of structure in this region, the coal beds are the best markers, and though not altogether reliable, the absence of better key beds makes their use imperative. Of the coals, Bed V is the most reliable, being persistent and recognizable over the entire coal-field area. This coal bed is accompanied by two thin limestones, which makes it readily recognizable. A number of coal beds above and below this one may be used. Where these beds do not outcrop, their positions usually may be determined by the large number of coal mines and coal test drill holes. In many cases a fold may be worked out on two or three of these beds. The Sommerville limestone, an easily distinguished bed, is exposed in parts of Vanderburgh and Gibson counties and may be used as a key horizon for structural determinations.

Gibson County is located at the southern end of the LaSalle anticline of Illinois, upon which are found the oil fields of the southeastern part of that state. It is not known what, if any, relation exists between the anticline and the structure of the individual pools of this county. It has been suggested that the origin of the Gibson

County structures is contemporaneous with that of the LaSalle anticline, though there is little evidence to substantiate this view. Subsurface studies show that the structure of the pools studied in Gibson County is of the anticlinal type. It has been thought that pre-Pennsylvanian folding accounts for these folds, as there is practically no evidence of them in the surface rocks. Possibly they are due to differential settling of the sediments. In at least two cases, folds originating in this manner have been definitely proved to exist in adjacent areas in the Pennsylvanian rocks. The writer believes that the first view as to the origin of these anticlines is the more tenable. In the east Princeton pool, there is strong evidence that a fault of considerable magnitude exists in the Mississippian rocks. Little drilling has yet been done in this pool, and more complete information is not available. The production from the Sullivan County fields comes from three different horizons in the Pennslyvanian and has been thought to come from sand lenses. Later studies prove that although the sands may be somewhat lenticular, there is undoubtedly a small amount of anticlinal folding. The extent of producing horizons in both the Chester and the Lower Pennsylvanian rocks is generally affected by the lenticular character of some of the sands and by irregular cementation.

NEW OIL POSSIBILITIES

There remains in the state much territory and a number of deeper formations which have possibilities for the production of oil. In the southwestern district, the Mississippian rocks below the Chester, the Devonian rocks below the New Albany shale (Chattanooga), the Silurian rocks, and the Trenton limestone have never been thoroughly tested on folds which are productive in the upper rocks. It is believed that these horizons offer sufficient possibilities to merit testing. Immediately beneath the New Albany shale, especially in the northern two-thirds of the state, there is a dolomitic horizon which produces oil in Jasper, Marion, and Vigo counties. In structurally favorable areas, possibilities are good for production at this horizon. A large sealed fault known as the Mount Carmel fault, with a throw of from 100 to 200 feet, traceable through parts of Hendricks, Morgan, Monroe, and Lawrence counties, offers possibilities

for production in the Devonian and Trenton. This fault is of the normal type with the downthrow on the west side, thus causing a reversal in the rocks, which normally dip to the west. Gas has been found at a number of points along this fault, and a showing of oil in one place. It is not unreasonable to assume that oil in commercial quantities may be found.

The surface structure of a large area of exposed Upper Mississippian rocks may be determined, as there are many easily distinguished horizons for use as markers. The surface rocks and the rocks below the surface are largely competent, and any fold found at the surface may be presumed to exist in the deeper Devonian, Silurian, and Ordovician, where there are formations which may contain oil. The Devonian is probably the most favorable horizon for production, as oil has been found in commercial quantities in these rocks at a number of places in the state. The depth to the Devonian varies, but it is nowhere deeper than 1,500 to 1,800 feet, and in many places it is little more than 1,000 feet deep. Few wells have been drilled to the Trenton in southwestern Indiana, for it is between 2,000 and 3,000 feet deep.

It is not expected that large wells will ever be found in Indiana, but it is believed that the amount of oil that may be found will warrant testing some of these deeper horizons which are known to be productive elsewhere. It is also believed that a more detailed geologic study of the southwestern counties will reveal additional areas that are unusually favorable for good production in the lower Pennsylvanian and Chester rocks.

THE STRUCTURE OF THE SALT DOMES OF NORTHWEST EUROPE AS REVEALED IN SALT MINES

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ABSTRACT

Salt-mining in Northwestern Europe has afforded significant data on the structure of salt domes. Salt is a relatively plastic rock under pressure, and may "erupt" in a manner analogous to igneous magmas. Highly deformed, clearly traceable key beds in the salt domes of Europe, and progressive changes from slight flowage at the salt outcrops to typical intrusive relations where the salt is deeply buried, afford basis for the conclusion that the European domes are purely tectonic in origin. The cap rock represents the residue of less soluble material in the upthrust salt as solution attacks the rising dome in the zone of active ground-water circulation. The salt domes of Europe are mostly without associated oil deposits, a feature probably due to pre-Eocene erosion which permitted escape of oil from older source beds.

INTRODUCTION

The following paper discusses briefly the structure of certain European salt domes which have been made accessible to students through the openings driven in the operation of mining for salt.

CHRONOLOGY OF SALT-DOME STUDIES

We have come gradually to realize more clearly that the structure of a complex series of rocks, exposed to tectonic forces, is influenced largely by the comparative rigidity of its component members. Following the pioneer work of A. Heim in 1878 and L. Milch in 1911, European investigators have spent considerable effort on this problem. The work of H. Cloos during the years 1918 to 1921, and, with special reference to masses of rock salt, H. Stille (1910 to 1923), E. Harbort (1910), and E. Seidl (1921) is notable.

THE NATURE OF PLASTIC FLOW

If rocks are classified on the basis of their rigidity, the opposite ends of the series are represented by fully indurated crystalline rocks on the one hand, and fluid magma on the other. The inter-

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mediate types are, in order of decreasing rigidity, metamorphics, consolidated or compacted sediments, and unconsolidated sediments. Among the processes which increase rigidity, compressive folding is a potent factor.

Rock salt and, to a lesser degree, gypsum and clastic rocks with a salty or gypseous cement possess a surprisingly high plasticity under pressure. If a plastic rock incased between more rigid materials is subjected to sufficient pressure, it reacts by flowing and escapes along lines of least resistance; in other words, it "erupts." Fluid magmas do this in a very conspicuous manner, but the behavior of rock salt is quite analogous and very similar. As shown by E. Harbort, salt "erupts" or "intrudes" as salt plugs which are extraordinarily like volcanic necks in some cases, and like laccolithic intrusions in others. Rock salt is not alone in its magma-like flowage, however; Mrazek has described similar intrusions of saliferous clays in the diapiric anticlines of Roumania; Zimmermann in 1889 noted similar phenomena in gypsiferous Triassic shales in Germany, and F. Ehrman in 1921 observed the same thing in the Atlas of Babors, Algeria.

Plasticity of this character varies greatly with depth: given a sufficient overburden, every rock, even the most rigid granite, exhibits plasticity. This plasticity is quite different from true fusion and is not to be confused with fusion. The more deeply a salt mass is buried, the greater the tendency toward the upward growth of salt "plugs," and the stronger the resemblance between these plugs and true volcanic plugs. Although in this manner isostasy plays an important part in the mechanics of salt-dome intrusion, isostasy alone does not afford a complete explanation of the phenomena. Cloos and Stille have both argued that the weight of the overburden merely makes the salt plastic; in order to move and deform it, tectonic stress also is required.

Stille has also observed the curious fact that during periods of orogenic quiet throughout which pronounced diastrophism (folding and thrusting) is lacking, and only block faulting and slow epeirogenic changes of level are to be observed, the plastic elements of the earth's crust continue to move, or even exhibit an increased tendency toward flowage and eruption. This tendency is especially

noticeable during plio-epeirogenic periods, i.e., periods of general submergence, and it applies not only to magmatic materials, but also to bodies of rock salt, which occupy a position intermediate between rigid crystalline rocks and magmas. While Stille showed that the upthrust of salt plugs marked periods of diastrophism, K. Gripp has also demonstrated that deep-seated, true "plugs" of salt also move upward during periods of tectonic quiet. Nevertheless, it should be repeated that lateral pressure is a requisite of salt-dome intrusion. If mere isostasy could develop them, we should find salt domes on the quietly stable continental plateaus like the Mid-Continent area of North America, parts of which, such as the western parts of Kansas, Oklahoma, and Texas, are underlain by great, deeply buried beds of rock salt.

THE CHARACTER OF EUROPEAN SALT DOMES

Figures presented by E. Seidl on the salt deposits of Northwestern Europe show in detail the deformation of the salt masses as revealed by extensive potash-mining. Because the valuable potash salts occur in thin beds intercalated with thicker zones of less valuable sodium chloride, mining engineers were obliged to pay especial attention to the structure and deformation of the salt plugs. This work was facilitated by the fact that the salt bed in question, which forms a great blanket deposit of Permian age, extending from Poland to the midlands of England, contains regular and easily distinguished alternations of anhydrite and clay. Particularly useful key beds of this nature are the thick anhydrite and gray clay, 150 feet in thickness, which separates the "upper salt," 600 feet thick, from the "lower salt," 900 feet thick.

The basins along the northern margin of the Paleozoic plateau of Central Europe and the great geosynclinal region of the North German and Baltic plains afford an opportunity to study the structure of salt masses under varying overburden, from the outcrops of the salt beds themselves against the older plateaus, to salt plugs which are squeezed up from depths of 18,000 feet. The structural types form an uninterrupted and continuous series, from slight deformations or flowage on the outcrops, to truly eruptive necks of salt in the region of Hamburg.

At the outcrops the salt merely flows out: the bed thickens where the overburden fails; while down the dip, where the weight increases, the material flows toward the outlet and the thickness of the salt bed decreases.

Where there is no natural outlet toward an outcrop, the salt escapes only at points of weakness. It forms truly laccolithic intrusions, taking advantage of points of weakness, entering the fault fissures, and forcing itself up in them, bulging and finally piercing the overlying strata. If an actual neck forms, it makes room for itself by pushing the sediments to one side and overthrusting the upper strata over the lower. At the same time salt continues to be fed into the plug from below, flowing into the base of the plug from all sides out of the Permian salt bed, which thins and sometimes is entirely squeezed out. These movements within the salt are made manifest by the contortions of the well-defined key horizons noted above. The cores from diamond-drill holes which were sunk through all the salt and into the underlying beds reveal all the salt, down to the base, contorted at high angles, but the underlying bedrock is horizontal.

THE NATURE OF CAP ROCK

Cap rock represents the residue from solution of the salt. As soon as the rising plug of rock salt nears the surface and enters the zone where subsurface waters are in motion, the upper part of the salt begins to go into solution. The top of the salt plug is evidently a solution plane. The folds in the salt mass are planed off sharply by it. We may compare it to the lower end of the glacier, where fusion balances the supply of ice. The top of the salt is the plane above which solution balances the up-push of salt from below. The least soluble impurities are concentrated to form a cap over the rising plug. Consequently, the thickness of the cap depends upon the amount of impurities contained in the salt dissolved, and upon the amount of upthrust after the zone of dissolving ground water is invaded by the upper part of the plug. In Europe the thickness of cap rocks varies from a few inches to 300 feet.

The character of the cap rock depends upon the nature of the impurities of the salt; it may be dolomite, anhydrite, or clay. Limestone or chalk overlying the salt may be altered to calcium

sulphate by sulphuric gases or waters, which are often associated with these structures. The cap rock itself may again be corroded by subsurface water, as is the case in many of the German salt domes, where large cavities so formed and filled with brine or quicksand caused great difficulty in the sinking of mine shafts.

The entire structure is so clear that there remains no vestige of doubt as to the origin of these European salt domes and *their purely tectonic nature.* We can follow the evolution step by step in the salt mines of Northwestern Europe.

OCCURRENCE OF PETROLEUM

The German salt domes are but rarely petroliferous. The most important oil field connected with any of them is that of Wietze. The primary source of the oil is probably in the Jurassic and Lower Cretaceous, from which various overlying sand beds have been impregnated. It must be assumed that many of these domes originally carried oil; however, most of them were subjected to active erosion before the deposition of the Eocene, so that the Upper Cretaceous covering of the oil-bearing formations was cut through and removed.

THE FILES OF THE OIL GEOLOGIST

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ABSTRACT

This paper gives a brief account of the author's method of filing data pertaining to oil-field investigation and development, with suggestions as to application to the general requirements of petroleum geologists.

INTRODUCTION

The more the data of an oil geologist on geological and economical matters increase, the more it becomes imperative to file them in such a way as to have all data instantly available for use. If these files are properly arranged, the geologist knows at once where to file new information to whatever country or locality it may appertain.

The writer does not remember ever having seen a paper on methods of properly filing such geological information as the geologist is constantly collecting and using, when studying the geology of countries, districts, or localities. It seems useful to initiate a discussion on filing methods for geologists by describing the filing system used by the writer, hoping that this may induce others to do likewise.

MATERIAL TO BE FILED

Not until the kind of material which has to be filed is known can the most efficient filing methods be outlined. It is therefore necessary to review shortly here the oil geologist's material concerning a special district or country. The most important geological and economical information on a region which an oil geologist needs can be divided conveniently as follows:

A. Geology
   1. List of publications
   2. General information
   3. Stratigraphy
   4. Tectonics

5. Oil indications, etc.
    a) Oil and gas seepages
    b) Oil and gas sands
    c) Occurrence of rock salt
    d) Salt-water springs
    e) Sulphur-water springs
    f) Other indications
6. Geological maps
7. Topographical maps
8. Statistics
    a) Production of the entire country or state
    b) Other statistics
9. Miscellaneous

B. Localities
(All information on those localities where either oil or gas occurs, or where wells are or were drilled, or where companies have taken leases)
1. Geology
    a) Stratigraphy
    b) Tectonics
    c) Geological maps
    d) Progress maps
2. Statistics
    a) Production of the locality
3. Properties
    a) Property map of the locality
4. Companies
    a) Properties
    b) Wells
    c) Statistics, etc.

C. Companies
1. General information
2. Capitalization
3. General list of properties
4. Property map
5. Statistics
6. Localities where the company has leases
    a) Property map
    b) Property sheets
    c) Drilling obligations
    d) Expiration of contracts, etc.

This list, even if not complete, gives an idea of the geologist's material and how to subdivide it. Additional material can easily be fitted into this scheme.

FILING SYSTEM

As a rule, the vertical filing system answers our needs best, but in some cases the additional use of a visible system, like the "Kardex" or the "Rand Visible," has some special advantages. In the following lines, however, only those files are discussed for which the vertical filing system is the most efficient one.

Folders of legal size are used, and it is of special advantage to use tapped folders instead of guide cards. The folders have either taps in three different positions or in five different positions. Third-cut folders are used for the main divisions and fifth-cut folders for further subdivision.

Generally speaking, each folder with the subsequent tap contains the subdivision of the material filed in the folder with the preceding tap. This system of using folders with the same tap for the same kind of material allows of inserting at any time new folders in the right alphabetical order. In the files "Localities," e.g., the files can be started by simply using the folders with the alphabet. Folders with the names of localities can be inserted and completed at any time, and those folders with further subdivisions are used only in case the material increases so much as to make a subdivision desirable.

FILES OF THE OIL GEOLOGIST

Naturally on some countries or other political divisions the geologists' data will be far more extensive than on others, therefore the filing system must allow the geologist to extend the original files as the material increases, without having to change the system.

General information on a continent is filed in third-cut folders with the first tap. In this same folder data on countries can be filed preliminarily if no special folders for these countries are yet available (Fig. 1). In case there are data on special countries to be filed, third-cut folders with the second tap should be inserted, with the names of the countries written on the taps (Fig. 2). As soon as the material concerning any one country increases very considerably, a subdivision of the respective country's files becomes advisable. Third-cut folder with the third tap is used for each of these subdivisions, and the names "Geology," "Localities," "Companies," and "Miscellaneous" are written on the taps (Fig. 3).

As regards countries in which the oil geologist is specially interested and on which he needs the most complete information not only concerning the geology of the country as a whole but also concerning the special geology of localities, the leasing, the operations, the companies, etc., a more detailed subdivision is required, and for this purpose fifth-cut folders are used. The paragraph on "the material to be filed" gives an example of the kind of headings that can be used for such subdivisions.

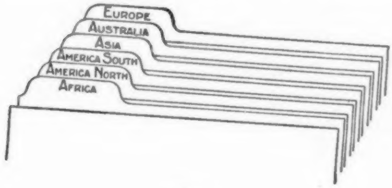

Fig. 1

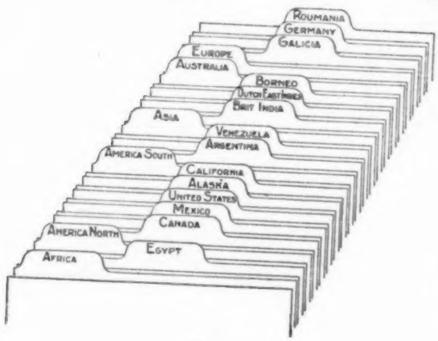

Fig. 2

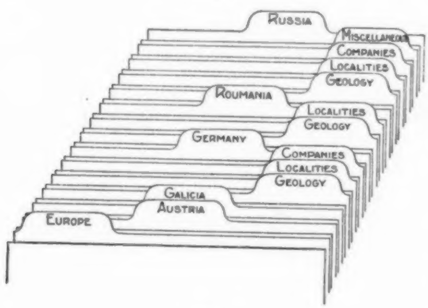

Fig. 3

Geological data on a country, which are of importance for the geology of the country in general, should be filed under "Geology." Here belongs not only information on regional stratigraphy and tectonics, but also general geological maps, lists of literature, etc., arranged as illustrated in Figure 4. Subdivisions of these items may be made by using fifth-cut folders with the fifth tap.

Those who wish to distinguish between the names of the formations, e.g., Devonian, Carboniferous, Permian, and their subdivisions, can easily mark the taps with paper of different colors. This

can be done either by pasting a small round piece of colored paper in the upper right corner of the tap, or by writing the names of the formations on paper of a special color and those of the subdivisions on paper of another color, afterward pasting these papers on the taps.

There is a special reason for using only fifth-cut folders with the fourth and fifth tap for the subdivision of the files "Geology." In the files "Localities," the folders with the first, second, and third taps are used for "Alphabet," "Localities," and "Companies," and,

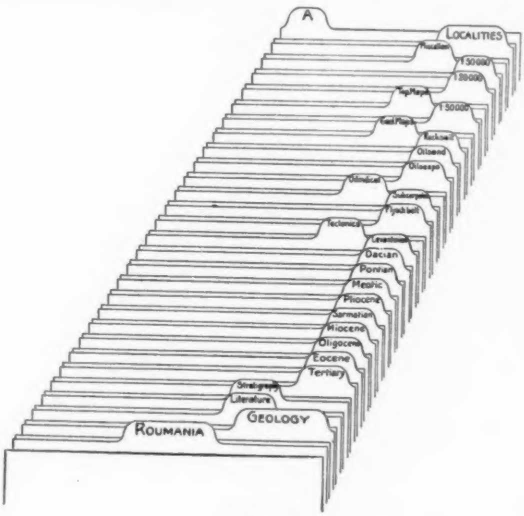

Fig. 4

therefore, only the folders with the fourth and fifth taps are available for the geology of the locality (Fig. 5). As it is essential to use folders with the same taps for the same subjects, the subdivisions of the files "Geology" are put throughout the whole files into folders with the fourth and fifth tap too.

Under "Localities" an alphabet is arranged by using fifth-cut folders with the first tap. The material concerning a special *locality* is filed in a fifth-cut folder with the second tap. It is obvious that not only special localities but also provinces, counties, and districts should be filed by using such folders with the second tap. It is to a

great extent a matter of personal taste, though also often depending on special circumstances, whether all the folders of localities as well as those of provinces, counties, and districts should be filed in alphabetical sequence or whether a first division should be made, say, in counties, filing behind each county the localities situated therein alphabetically in their turn. The first method allows of finding any locality at once, whereas the second method presupposes the knowledge in which county the locality is situated. If it is required to know

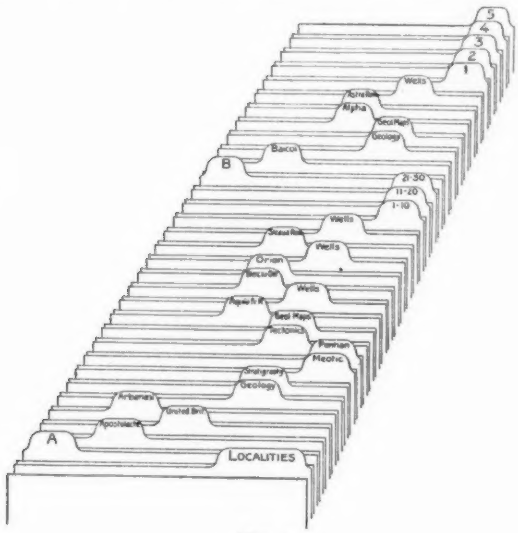

FIG. 5

at once which localities lying in a special county have special files, a colored reference chart containing the names of these localities is put into the folder of the county.

Data on localities which as yet have no special folders are filed in the folder of the corresponding alphabetic letter until such time as the information increases so as to justify a special folder with the name of the locality.

Each company having leases in a special district, or locality, should have a special folder, which will contain information on the

geology of such leases, on the wells—if there are any—on production, etc. Whether it is necessary to make subdivisions using folders with the fourth tap and further subdivisions using folders with the fifth tap depends on the amount of information available on a company's holdings in the locality and especially on the wells. The information on leases and on wells can, e.g., easily be separated by using folders with the fourth tap for both. Most of the material will, however, concern the own company, and this material, therefore, needs a more detailed subdivision.

Every single well which the own company possesses in any locality should have a special fifth-cut folder with the fifth tap, and this folder should contain every information on this well, thus a complete well history.

Folders with the fourth tap marked "Geology" are inserted to contain all information on the special geology of the localities, also geological maps, etc. In case the information and the number of maps increases too much, they are separated into folders with the fifth tap. If much detailed information is available, the "Geology" can be closely subdivided and each map can be put into a separate folder with the fifth tap, using a folder with the fourth tap marked with "Geological Maps" as guide. Figure 5 illustrates the files "Localities" so far as Roumania is concerned.

It is necessary to indicate on the folders the place where they belong to, to facilitate replacing them, in case they have been taken out of the files. The following examples give an idea how this identification can be carried out either by writing the names directly on the folders or by writing them on colored paper and pasting the paper on the folders. The examples are taken from the files "Localities" of Roumania.

For "Companies" fifth-cut folders with the first tap are used as alphabet and the names of those companies in a country for which special files are described are written on folders with the second tap. In these files special information on the companies will be filed which concerns all localities, e.g., property lists, maps showing the holdings, notes on capitalization, statistics, etc.

The subdivision has to be very detailed, especially as far as the own company is concerned. Each locality where the own company

has holdings should have a special folder (with third tap), and further subdivisions can be arranged, e.g., one folder with the fourth tap for each locality marked "Leases" or "Properties," and folders with the fifth tap indicated with "1-10," "11–20," "21–30," etc., con-

a) Folder with first tap: Alphabet.

B
Country: Roumania
Files : Localities

b) Folder with second tap: Localities.

Baicoi
Country: Roumania
Files : Localities

c) Folder with third tap: Companies.

Steaua Romana
Locality: Baicoi
Country: Roumania
Files : Localities

d) Folder with fourth tap: Wells.

Wells
Company: Steaua Romana
Locality : Baicoi
Country : Roumania
Files : Localities

e) Folder with fifth tap: No. of Wells.

Well No. 15
Company: Steaua Romana
Locality : Baicoi
Country : Roumania
Files : Localities

taining the property sheets, etc., of the leases Nos. 1–10, 11–20, 21–30, etc. On these property sheets all the necessary data are recorded, e.g., name of owner, area in hectares or acres, yearly rental, drilling obligations, duration of contract, most important clauses of contract, etc.

A special list containing all the drilling obligations can be filed in a folder with the fourth tap, marked "Drilling Obligations." The map, showing the holdings of the company in a special locality, will be filed in the folder marked with the name of the locality on the third tap, mentioned above.

Figure 6 illustrates the file "Companies" so far as Roumania is concerned.

It depends on the conditions in the various countries and on the personal taste how these subdivisions should be arranged. In any case, it is easy to find the most efficient way if it is considered that

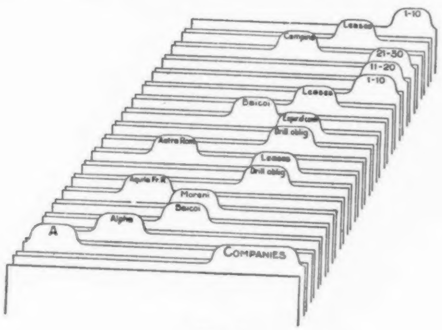

FIG. 6

analogous material should always be filed in fifth-cut folders with the same tap.

Miscellaneous.—There are plenty of data which are of importance to the oil geologist, and which cannot be filed under the third files, "Geology," "Localities," and "Companies." All these are filed under "Miscellaneous."

It would lead me too far if I were to enter into all the possible details of these files, as they vary greatly according to the special interests of the geologist. The same principles discussed in the foregoing chapters should, however, also be applied to these files. The folders with the first tap should be marked with the alphabet, and the folders with the second tap should bear the names of the main subjects, every folder with the subsequent tap to contain the subdivision of the preceding one.

GEOLOGICAL NOTES

THE VALUE OF RELIEF MODELS AND A SIMPLE METHOD FOR THEIR CONSTRUCTION

The writer has observed that when the origin and local relations of parts of a geologic structure are not clearly seen from a study of the surface or subsurface contour map, a model of the structure has been of much value. In a large number of instances models are not worth their construction, especially when the structure is simple. However, where faults, sharp synclines, terraces, and other such features are present, the model becomes of much service in studying the relation of any one of them to the whole. This is more especially true when the structure is large. The model does not show anything that is not on the contour map, but it does show a single or series of features in relation to the whole that is not readily obtained from the map. To the official or client not thoroughly acquainted with reading a contour map, the relief model is of great benefit in showing structural features. The chief objection to models has been the time required and the materials necessary for their construction. The writer has used a simple and inexpensive method which does not require a great deal of time or skill, which is here described for those who may be interested.

The materials necessary are a print of the contour map, a smooth board of soft wood a little larger than the map, a few pounds of different-sized finishing-nails, library paste, hammer, plaster of Paris, a pocket knife, sandpaper, paint and varnish, and a brush.

The board selected should have a smooth surface, and be of soft wood, about an inch thick, square, and cleated on the back to prevent warping. A drawing-board is excellent for the purpose. The map is soaked in water, the back covered with thin paste, and then spread out on the board, after which the wrinkles are smoothed and it is allowed to dry. A vertical scale is chosen for the relief. In selecting the scale the total relief should be the controlling factor. Where the relief is 200 feet or more on large models, a scale of 1 inch = 200 feet has been found satisfactory. If the relief is small, the scale may be increased to 1 inch = 100 feet in order to bring out more clearly the minor features. In all cases, too much vertical exaggeration should be avoided, although it should be generous enough to bring out the features desired.

The surface of the model is used as the lowest contour line, this being the working datum for the model. The nails are driven into the board on the contour lines or in between them at the proper distance where the dip is very low, their extension above the board being controlled by the contour line on which they are driven. For example, assume that the total relief of the structure is 100

feet, that is, the lowest contour line is 900 feet and the highest, 1,000 feet. The surface of the board then represents the 900-foot level or contour line, and no nails are driven on this line. On the 925-foot line the nails extend above the board $\frac{1}{4}$ inch, on the 950-foot line, $\frac{1}{2}$ inch above the board, and so on, the 1,000-foot line being represented by nails extending 1 inch above the surface of the board. Nails of different length should be used in order to avoid driving them too deep in the board. It has been found that a nail should be driven on at least every square inch of the board, and where the relief is great or where sharp, there should be driven enough nails to bring out the contour of the structure. After all the nails are driven, their tops represent a surface conformable to the structure as drawn on the map.

Plaster of Paris is now mixed and poured around the nails, just covering them. A grade known as "dental plaster" is best for models, as it is very fine and white and sets rather quickly. Within an hour or so after the plaster has been applied, the nails will have rusted enough to show through the plaster so that they may be found when the working-down begins. In working down the surface to the tops of the nails, a pocket knife with a large blade has been found very satisfactory; however, any one of a number of tools may be used. When the plaster is dried, sandpaper is of use in making the surface smoother than can be done with the knife. To fill up air holes and those places that have been cut too deep with the knife, a very thin slurry of plaster may be applied with a brush or the palm of the hand. The application of this slurry also re-covers the heads of nails which may have been exposed in the working-down process.

The part of the print which extends beyond the plaster is now removed, the board cleaned off, and the plaster allowed to dry still more. Before the print is removed, however, it is advisable to drive some small brads in the board on the section corners and lines for guides, so that these may be drawn on the model after it has been painted.

The surface of the model is sized with a mixture of one-half white paint and one-half varnish. Two coats of flat white and two coats of varnish are then successively applied. This type of surface is satisfactory for india-ink lines and lettering. The legend is drawn on the surface of the board.

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BEDS OF VOLCANIC MATERIAL AS KEY HORIZONS[1]

Beds of volcanic materials are attracting the attention of geologists, who are using them as key horizons in stratigraphic correlation. This is shown by the increasing number of papers on the subject that are published, especially within the last few years.

Explosive eruptions often spread volcanic débris over very large areas, and the volume of material ejected may reach stupendous proportions. If the ash is deposited directly from the air, the resulting bed will be continuous and may

[1] Published by permission of the United States Geological Survey.

present the same characteristics even when other closely associated beds are entirely dissimilar. The ash may fall on land and later be re-worked and redeposited in the sea, but even then the resulting beds may not differ from one another in age. These characteristics make volcanic horizons ideal key beds in many ways, and therefore they appeal to geologists, who are ever on the lookout for a useful tool that can be used in their science. But do they offer such a tool? Are volcanic horizons reliable key beds that provide a workable method of correlation; and if they do, how are they to be used, and what are the precautions to be taken against misinterpretation?

Explosive volcanic eruptions that form extensive ash beds are commonly composed of silicic or alkalic types of rocks, and the tuffs that they form are often glassy. Under certain conditions, which it is not easy to postulate, glassy tuffs are subject to a very characteristic type of alteration whereby the glass is devitrified and at the same time most of the bases and part of the silica are removed in solution, so that there is a relative increase in alumina. During this process any phenocrysts that may have formed in the rock previous to eruption are likely to remain unaltered, so that quartz, feldspar, mica, and even augite may be entirely fresh. The resulting material is a bentonite composed of a claylike ground-mass containing various amounts of crystalline grains. Beds of bentonite having such an origin are abundant in nearly all the western United States, but it is becoming evident that they are widespread in all geologic ages, and probably in all regions.

Bentonite has very peculiar properties that are causing it to be investigated and used in a great variety of industries, but the stratigrapher is interested only in the features that will enable him to recognize it. Bentonite may have almost any color, and shades of gray, brown, pink, yellow, green, and white are common. When placed in water it may slowly swell into a plastic or gel-like mass, but more often it swells slightly and slacks, or crumbles, and it usually does this without becoming markedly plastic. Under the microscope the ground-mass of a typical bentonite is revealed as a more or less smearlike aggregate of crystalline material. The claylike mineral of the ground-mass is distinctly micaceous in habit, and the birefringence perpendicular to the cleavage is about like that of a mica. The texture varies greatly and in some specimens it is almost submicroscopic, but in others it is so coarse that the rock resembles a sericite schist. If the bentonite is derived from a tuff that has not been re-worked, the original tuff structure is often perfectly preserved.

Beds of high-grade bentonite are fairly characteristic and will usually be recognized without much trouble. Many ash beds, however, are composed of material that fell on land and that was later re-worked and more or less completely mixed with other rock débris. It is this kind of material that the stratigrapher will probably most often meet and be called upon to correlate.

The interest in bentonite is so great that for a number of years an important part of the work in petrology on the U. S. Geological Survey has consisted in examining and reporting on bentonites, bentonitic arkoses, and volcanic ash.

Large numbers of thin sections have been cut, structures have been studied, and indices of refraction have been determined on a great variety of specimens, and yet no criteria have been discovered which will permit a certain identification of this type of material. Sometimes it can be stated positively that the material has had a volcanic origin, but often the answer is "probably volcanic" or "undeterminable."

Tuffaceous structure or small fragments of recognizably volcanic rocks are conclusive evidence of volcanic origin. The presence of euhedral and especially of zoned crystals of feldspar, of biotite, and of euhedral augite is very suggestive of volcanic material but is not altogether conclusive. The presence of the micaceous claylike mineral that is so characteristic of bentonite points toward a volcanic origin, but it is not conclusive, for some sedimentary clays have a micaceous claylike base. A careful microscopic examination is the best test of a volcanic origin, but even then the tuff structure is often very elusive and hard to recognize. The peculiar property that bentonites have of crumbling in water is fairly characteristic but should not be considered conclusive. Some of the tuff-derived materials do not show this property, or only after drying and re-wetting, and calcite-cemented bentonites do not show it at all. On the other hand, sandy clays and shales may crumble in water. Tuffs have been observed which were almost completely replaced with calcite and resembled a limestone, but even in these the volcanic structures may be preserved. Arkosic sands may come either from volcanic tuffs that have been sorted or from much older igneous rocks. The sands may contain mixtures of material derived from plutonic, metamorphic, or volcanic rocks, or from volcanic ash. In the study of some horizons it has been necessary to separate and determine the heavy minerals, and to examine the sands for individual rock grains. Euhedral augite is most likely to come from volcanic ash; hornblende may come from volcanic rocks but is more likely to be derived from granitic types of rock; tourmaline and garnet indicate metamorphic rocks. The writer had occasion to study arkosic sands from Montana which had all these types of minerals; and these gave evidence of a very mixed origin. The sands contained a small proportion of bentonitic material, but it was concluded that volcanic material was present only after a careful search had revealed a few grains of volcanic rock. Thus the problem of identification may be very complex and involve an approach from several angles.

When volcanic action is long continued, many similar beds may be produced, and when large amounts of ash fall upon land it may be redeposited in several successive beds. In either case there may be so many similar horizons of ash that none can be safely used as a key bed.

In conclusion it may be said that volcanic horizons will undoubtedly be useful in correlation and should be looked for and used whenever possible. The problem of identification will often involve many difficulties and pitfalls; hence serious mistakes are possible. Above all, we must go slowly and not discredit a promising method of correlation by giving it unjustified reliance.

CLARENCE S. ROSS

U. S. GEOLOGICAL SURVEY

VOLCANIC TUFFS IN CENTRAL OKLAHOMA

Two outcrops of volcanic tuffs have been noted in T. 15 N., R. 5 W., near Cashion, Oklahoma, one in the northwest quarter of Section 10 and the other in the southeast quarter of Section 2.

The outcrop in Section 10 is about 150 feet long, extending north and south, and is the surface bed immediately overlying Permian red beds. Some of the volcanic material is partially indurated and breaks into pieces about the size of a man's head. These pieces are very light in weight for their size and are quite porous. The unindurated material is very finely powdered and feels like flour when rubbed between the fingers. Both the fine powder and the pieces are white in color.

The outcrop in Section 2 is much larger. It can be seen about ½ mile west of Cashion on the main road leading west, where a cut about 8 feet deep exposes the bed for about 300 feet, and in a field to the north. The tuff is about 3 feet thick and grades into the Permian red shale below and residual material above. Through the middle of the bed is a semi-indurated layer approximately 5 inches thick, which makes a ledge. The bed is unevenly colored with a mixture of white and grays. Its character is very similar to the outcrop in Section 10.

The writer collected samples at both places and sent them to Professor Albert Johannsen, of the University of Chicago, for examination. He reports that they are very nearly pure volcanic tuffs, being made up of many small white to colorless, transparent angular bits of volcanic glass.

The known widespread distribution of similar deposits in various parts of the plains country and the purity of the material indicates transportation by wind from a distant source.

Malvin G. Hoffman

February 10, 1925

QUARTZITE PEBBLES AT THE BASE OF THE LANCE FORMATION IN MONTANA

Of geological interest is the recent discovery by the writer of quartzite pebbles, one-half inch to three inches or more in diameter, at the base of the Lance formation in east central Montana. Most of the pebbles are of light-buff quartzite, but several porphyry pebbles were also found. The occurrence was noted while mapping the Freedom dome, about 15 miles south of Jordan, in Garfield County. Here, the Hell Creek member of the Lance formation rests on well-bedded sandstone and shale which ranges in thickness from 35 to 66 feet. This, in turn, lies upon dark shale of the Bearpaw formation, as determined from the lithology, stratigraphic posi-

tion, and fossil content of this formation. About 100 feet of typical Bearpaw is exposed in the center of the dome.

A typical section of the strata exposed, involving the quartzite pebbles, is given below:

Formation	Thickness (Feet)
Lance formation, Hell Creek member	
Masses of brown sandstone imbedded in gray sandy shale (contains many fragments of dinosaur bones)	40+
Brown sandstone in loglike masses, imbedded in soft, light-brown sand	10–12
Soft, light-brown sand	4–6
Limonite bed containing quartzite and igneous pebbles	$\frac{1}{2}$
	$54\frac{1}{2}$–$58\frac{1}{2}$+
Fox Hills (?)	
White sandstone, soft	6–12
Alternating beds of light-gray shale and light sandstone averaging 1 foot each	21
Limestone concretions, light gray, sandy, carrying fossils in places	1–2
Light-gray shale, sandy	8
Alternating beds of sand and light-gray shale averaging 3 inches each	5
Gray sand containing a streak of bright-yellow and magenta sand, contains nodules of pyrite	1
	42–50
Bearpaw shale	
Shale, dark gray to dark brown	22
Shale, gray, containing yellow clay bands	4
Limestone concretions, very dark brown on weathering, contain some baculite and scaphites	1
Dark-brown shale	10
	37+

The above section is representative of the strata in T. 16 N., R. 38 E., and the pebble bed could be traced for long distances around the Freedom dome. The pebbles are imbedded in impure limonite which also contains a small amount of coarse sand. The thickness of the bed where studied varies from 3 to 8 inches. In only one case were any foreign pebbles found at any other horizon in either the Lance or Fox Hills (?), and that was an isolated quartzite pebble about 1 inch in diameter imbedded in the hard, loglike sandstone about 10 feet above the Lance-Fox Hills contact. The contact does not seem very irregular at this place, and indications of chan-

neling are rare, though the varying thickness of the Fox Hills (?) indicates a slightly undulating surface upon which the earliest Lance strata were deposited, suggesting a local unconformity at least.

This is the only place in the Great Plains region where the writer has found pebbles of foreign origin at this stratigraphic horizon. The pebbles probably owe their origin to pre-Cambrian rocks of an old land mass, which is now buried and its position unknown.

C. MAX BAUER

BILLINGS, MONTANA
December 6, 1924

OIL WELL IN SOUTHERN FRANCE[1]

Oil was discovered at Gabian, Department of Herault, on September 11, 1924, and a commercial well was completed on November 6 at a depth of 350 feet. It is owned by the government and is in the center of a 4,000-hectare (15 square miles) concession in charge of the Direction des Pétroles. This is the first oil produced in France elsewhere than Pechelbronn, in Alsace. Gabian is 30 miles west of Montpellier and 19 miles north of the Mediterranean Sea.

An oil seepage in a spring ¼ mile south of Gabian was described in 1717. Later galleries were dug, and in 1880 and 1890 wells were drilled to depths of 1,360 and 600 feet, respectively, without success. The new well (Fig. 1) was located by geologists, MM. Barrabé and Viennot, of L'École Normale, on the projection of an anticline south of Gabian and between the basalt-capped hills. The seepage is at the contact of Upper Triassic (Keuper) marls and Triassic sandstones below, and the well was located on the marls in order to reach the sandstones under cover.

The well was spudded August 20, 1924, and had a showing on September 11 at a depth of 320 feet, where casing was set, although no water was encountered in the Keuper. The well was drilled ahead slowly and cored. The first core was cavernous dolomite containing drops of oil interbedded with sandstone. The same formation was found to 346 feet. A hard shell was found, and when the drill passed through it at 350 feet (106 m. 75), the well flowed for 15 minutes to a height of 20 feet. After 2½ hours it flowed 12 barrels.

The well has not been deepened. On November 24 it was flowing 90 barrels a day and had produced 1,570 barrels (average 105 barrels a day).

[1] This review is compiled from the following sources: "Le champ pétrolifère de Gabian," *L'Illustration* (Paris), November 29, 1924, p. 498; "Oil in Southern France," *Oil News* (London), January 31, 1925; P. Martignan, "Oil Developments in France," *Amer. Inst. Min. and Met. Eng., Production of Petroleum in 1924*, February, 1925.

A pump was installed in December and 562 barrels were produced the first half of January, the average daily yield at the end of this time being 32 barrels, pumping every half-hour in daylight only. The full capacity of the well is estimated at 190 barrels, but no thorough test has been made. Another report gives the daily production at 120 barrels the first of February.

The oil is 37.5° Baumé gravity (corrected to 60° F., A.P.I. scale), paraffin base. It congeals at 54° F. and requires heating in cold weather,

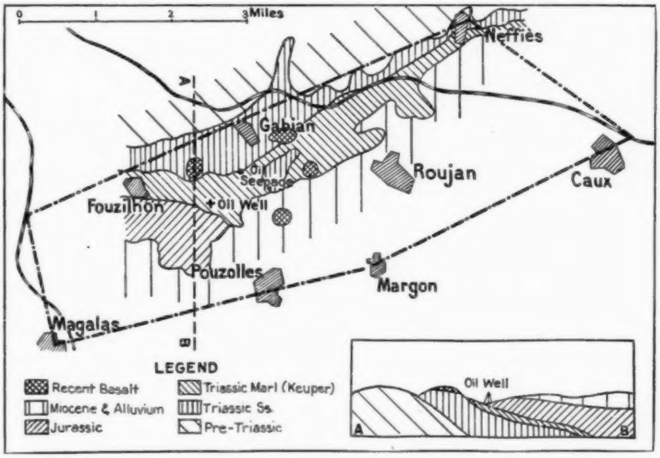

FIG. 1.—Geological map of the government oil concession at Gabian, Department of Herault, France, showing location of the new oil well. (From *L'Illustration*, Nov. 29, 1924.)

like the oil in the Texas Panhandle, which congeals at 60° F. These oils are alike also in being high in lubricants, the Gabian oil containing only 5 per cent naphtha. An analysis is given by Martignan.

Two other wells are being drilled at Gabian. The first of these was 218 feet deep the last of January and had passed through three water sands. The other drilling well was spudded about January 25. The oil well was drilled by the Rackey system. One of the new wells is a cable-tool test, the other a rotary rig.

A new oil well, 410 miles from previous production and in a stratigraphic section from which oil has never before been produced, is of great importance even though the discovery well is small. It indicates the possi-

bility of production throughout Southern France, and especially in the Aquitaine Basin between the Pyrenees Mountains and the Massif Central. Several wells are being drilled elsewhere in France; one is in the Limagne, near Clermont-Ferrand, where there are oil seepages in Oligocene rocks and in a conglomerate derived from volcanic rocks.[1]

SIDNEY POWERS

February 21, 1925

DISCOVERY OF POTASH SALTS AND FOSSIL ALGAE IN TEXAS SALT DOME

A core of rock salt containing potassium salts and fossil algae was recently taken, at a depth of 4,800 feet, from Gray No. 1 well of the Rycade Oil Corporation at the Markham, Texas, salt dome. This is the first occurrence of potassium salts reported from the salt domes of the United States, and is probably the most important contribution of fact to a study of their origin for a score of years.

The first appreciable step toward a knowledge of the real structure of the domes was the discovery of the main salt mass of Petite Anse, one of the Five Islands of Louisiana, by the deepening of an old brine well in 1862. We came to know the general form, composition, and structure of our domes as a result of the vigorous drilling campaign which followed close upon the discovery of an oil pool on the Spindletop dome in 1901. The active exploration of the domes since that time, in the mining of oil, sulphur, and salt, has served chiefly to emphasize the essential regularity of the domes, their general conformability to type, and to emphasize the uplift of the overlying and contiguous strata by the formation of the salt core and cap rock of the dome.

The first theories of origin—little more than vague speculations based on entirely inadequate conceptions of the true nature of the domes—regarded them as old Cretaceous outliers in Tertiary seas. With a fairly satisfactory working knowledge of the true constitution of the domes came Robert T. Hill's theory of precipitation of the salt and cap rock from solution in circulating waters. This theory, as elaborated and modified by Gilbert D. Harris with an appeal to the little-understood force exerted by growing crystals as sufficient to account for the uplift of the sedimentary rocks overlying and contiguous to the salt, received wide acceptance among American geologists and is still held by many.

[1] A. Werenfels, "Exploration for Petroleum in the Limagne, France," *Amer. Inst. Min. and Met. Eng., Trans.*, 1925.

Oil deposits of commercial importance were found in sands deep on the flank of the Humble salt dome in 1913–14; since which time, until quite recently, exploration has been directed chiefly to prospecting the flanks of the domes. The data obtained from such operations stressed the structural effect of dome formation, and salt-dome students began to feel that the Hill-Harris theory of precipitation of the salt cores from solution did not satisfactorily explain the very considerable and highly localized uplift occasioned by the formation of the salt masses. Hahn, as early as 1912, considered the apparent genetic similarity between American salt domes and various European and African salt structures, and Turrentine, in 1913, suggested that some form of the European theory of the formation of salt structures by flow of originally bedded salt under pressure was a theory whose assumptions were less violent than those yet proposed to explain the origin of the American domes. Van der Gracht, in 1917, and Dumble, G. Sherburne Rogers, and the writer, in 1918, expressed themselves in favor of theories of intrusive origin, and some form of such theory has since come generally to be accepted by salt-dome students.

Running through the entire period of our speculations on this interesting subject, however, have been various appeals to volcanism to account for the formation of the domes. These theories of volcanic origin apparently arise from the fact that structurally, a volcanic neck or plug is the only known geological feature which even remotely resembles a salt dome. Lee Hager, Veatch, Clapp, Dumble, Deussen, Oliver B. Hopkins, Lucas, and Washburne have at one time or another expressed themselves as favorably inclined toward theories of volcanic origin. Most of the theories are variations of the solution theories, regarding the salt as precipitated from waters of volcanic origin. Dumble appeals to the same forces which give rise to lava pockets as indicating greater plasticity or mobility in deeply buried bedded salt, a variation of the theory of formation of the domes by flow of salt under pressure.

The chief objection to the theories of dome formation by the flow of salt under pressure has been the lack of evidence for the existence of deeply buried bed deposits of salt of sedimentary origin postulated by such theories. The importance of the potash and algae-bearing salt discoveries is that they constitute positive, if not conclusive, proof of the sedimentary origin of the salt of the domes and establish the validity of the theory of the formation of the domes by flow of the salt.

E. DeGolyer

New York
January 29, 1925

THE RED BEDS NEAR THE BASE OF THE CHEROKEE SHALES

A recent article by Frank Greene[1] is of great interest to the writer because of his study of the so-called "Bartlesville" sand in parts of northern Oklahoma and southern Kansas. As stated by Greene, red shale beds occur in Lincoln, Payne, Pawnee, Noble, and Kay counties, Oklahoma, and Cowley, Chautauqua, and Elk counties, Kansas. They are also found in many other counties in both Kansas and Oklahoma.

A peculiarity of these red beds is their association with the "Bartlesville" sand of several oil pools, such as the Burbank, Rainbow Bend, Eastman, Fox Bush, Sallyards, Teeter, Thrall, Seely, etc. This correlation is generally made, and, though conceded to be one of convenience, is based on the position in the sedimentary column, the character of the sand, its oil, and the staying qualities of the production. Almost always, the red beds are absent when the sand is found and seem to take its place elsewhere, although red material is occasionally found closely associated with the sand.

It does not seem to be known generally that green shale is quite often found with the red. Red and green colors in sediments are due to the degree of oxidation of the iron which is present.

At the beginning of Pennsylvanian sedimentation, the Cherokee sea covered a large part of Oklahoma and Kansas for a period of time sufficient to deposit varying amounts of shale, and it then retreated. If, at that time, conditions were right for the type of oxidation which would produce a red or green color in the shales of the old sea floor, then the formations of the red beds would occur. Following this period of erosion and weathering, the sea readvanced rather rapidly, stopping one or more times for a long enough time to build a persistent beach line. This sequence of events will satisfactorily explain the relation of the "Bartlesville" sand to the associated red beds.

A dry hole, in which the writer was interested, was drilled in search of the "Bartlesville" sand south of the Eastman pool of Cowley County, Kansas. This well found a sandy zone 100 feet thick, about 40 feet above the Mississippi lime, which contained 6 feet of magnetiferous sand, some fine sand, and a good deal of sandy shale, together with considerable amounts of red and green sandy shale and shale. Six and five eighths-inch casing was set about 10 feet in this zone. Thirty feet deeper, a sample of white sandy shale was obtained from the cuttings, in which the writer found a well-preserved *Fusulina*. This was shown to Mr. D. K. Greger, of the Carter Oil Company, who identified it as Pennsylvanian in age,

[1] This *Bulletin*, Vol. 7 (1923), No. 6.

Fusulina being unknown in the Mississippian. Since red- and green-colored material was found with this fossil, the possibility that these red beds are of Chester age is precluded, and they must be placed in the Pennsylvanian.

This occurrence proves that the "Bartlesville" sand and its associated red rock is of lower Cherokee age and merely represents a small break in the sedimentary column. However, when one realizes the number and type of oil pools producing from this horizon, and accepts the theory that its oil production is controlled almost entirely by the presence of the sands of one or more buried beach lines, he appreciates the importance of this disconformity and has a rough method available for use in future explorations.

RUSSELL S. TARR

TULSA, OKLAHOMA

GRANITE WELLS IN THE NORTHERN MID-CONTINENT REGION

Several lists of granite wells have been published, but are now out of date, owing to the rapid increase lately in the number of such completions. The theory that granite will be found at abnormally shallow depths on domes and anticlines has been proven in so many instances that most geologists now accept it as a fact. In northeastern Oklahoma, the normal depth to granite, that is, the depth at points where the strata have not been folded, averages about 1,900 feet below the top of the Boone or Mississippian limestone.

In presenting this list (Table I) it is not intended that it shall be taken as a complete list, but rather as an attempt to provide in convenient form a summary of the pertinent facts in the hope that information may be added to that here brought together.

The greatest difficulty in compiling this list has been to obtain the correct depth at which granite was encountered. Where cuttings are not available, the correct depth will always be a matter of conjecture, and where they are available, even experts will sometimes disagree as to whether the cuttings are arkose, weathered granite, or true unweathered granite. Obviously a driller, or a geologist merely working with logs, cannot draw correct conclusions.

The writer will greatly appreciate receiving corrections and additions to the appended list, with a view to making it as accurate and complete as possible.

F. C. GREENE

TULSA, OKLAHOMA
November, 1924

TABLE I

Granite Wells in the Northern Mid-Continent Region

Company	Farm*	No.	Section	Township	Range	Location†	Elevation (Feet)	Date Completed	Granite at (Feet)	Total Depth (Feet)
						Oklahoma				
Marland Ref.	J. Joynson	1	18	28 N.	3 E.	C NE. SE.	1,171	May 18, 1920	4,800	4,826
Carter Oil	NW. ¼	1	9	26 N.	6 E.	C NW. NW. NW.	1,023	July 16, 1924	4,234	4,241
Cosden O. & G.	S. Barnett	17	22	17 N.	7 E.	NE. c NW. SE.	......	Mar. 13, 1921	3,670	3,704
Red Bank Oil	NW. ¼	2	14	22 N.	8 E.	SW. c SE. NW.	......	Mar. 9, 1923	3,422	3,429
Prairie O. & G.	SE. ¼	12	25	23 N.	8 E.	SW. c NE. SE.	......	Aug. 1, 1922	2,545	3,037
Marland Ref. & Kay Co. Gas	NE. ¼	1	16	24 N.	8 E.	SE. c NE.	......	Sept. 7, 1923	2,480	2,586
Gled Oil *et al.*	NE. ¼	3	16	24 N.	8 E.	SE. c NE. NE.	......	June 14, 1924	2,708	2,720
Gypsy Oil	Ethel Bryant	8	18	27 N.	8 E.	C NE. SE. SE.	......	Oct. 12, 1920	2,756	3,444
C. L. McCune	SE. ¼	......	3	21 N.	9 E.	SW. c SW.	......	May 25, 1920	2,757?	2,845
Finance Oil & Foster & Davis	SE. ¼	34	19	21 N.	9 E.	SW. c SE.	......	Feb. 8, 1921	3,200	3,202
Tidal Osage Oil	NE. ¼	18	32	22 N.	10 E.	1320′ S.–810′ W. of NE. ¼	......	Apr. 8, 1924	2,217	2,222
Tidal Osage Oil	NE. ¼	20	32	22 N.	10 E.	350′ N.–906′ W. of SE. c	......	May 8, 1924	2,240	2,290
J. F. Sweeney & Co.	Leva Husky	1	22	19 N.	11 E.	C SW. SE.	770 ap.	Feb. 10, 1921	2,867	3,071
Amerada Pet.	SE. ¼	1	7	23 N.	11 E.	NE. c SE.	......	Apr. 26, 1924	2,359	2,384
Dixie Oil	SE. ¼	7	30	24 N.	11 E.	C E. line SE.	......	Nov. 25, 1923	1,745	1,864
......	......	......	8	20 N.	12 E.	......	......	......	2,213	2,218
Barnsdall Oil	NW. ¼	23	9	20 N.	12 E.	C W. line NW.	......	May 3, 1924	2,424	2,435
Empire G. & F.	McElmore	3	25	25 N.	12 E.	......	750	Feb. 11, 1917	2,340	2,368
Superior Oil	Blakemore	1	26	21 N.	13 E.	875′ N.–50′ E. of SW. c	......	Oct. 21, 1924	1,365	1,462
J. C. Bixler	Sears	1	10	25 N.	13 E.	NE. c SE.	......	Apr. 1, 1923	2,333	2,400
Barnsdall Oil	Rigdon	7	30	28 N.	13 E.	C SW.	......	Dec. 20, 1920	2,548	2,560
Consumers Gas	Thomason	1	22	29 N.	13 E.	......	775	Feb. 3, 1917	2,500	3,175
H. F. Wilcox O. & G.	Hulputta	1	27	17 N.	14 E.	NW. c NW.	......	June 28, 1923	3,365	3,400
J. W. Irwin	Cox	1	23	20 N.	14 E.	NE. c SW.	......	May 31, 1922	3,190	3,360
Duquesne O. & G.	Doublehead	1	31	22 N.	15 E.	NE. c SE.	......	June 30, 1911	1,785	2,765
......	......	......	26	22 N.	16 E.	......	......	......	Report of granite	......
Prairie O. & G.	Security fee	105	27	27 N.	16 E.	SW. c SE. SW.	......	Dec. 5, 1916	1,955	2,070
......	......	......	13?	20 N.	17 E.	Near Scaly Bark Mtn.	......	......	1,226	......
Layne & Farnsworth	Fleming	1	35	20 N.	17 E.	SW. c SE. NW.	672 ap.	Oct. 1, 1921	495	527
E. C. Lantz	R. L. Rulison	1	4	15 N.	18 E.	C N. line NW.	......	May, 1923	2,970	4,605
H. F. Campbell	Tilly	1	28	15 N.	19 E.	NW. c SE. NE. SW.	......	Apr. 13, 1923	3,373	3,690
......	......	......	24	24 N.	19 E.	......	710	......	Granite reported	......
......	Ada Siegel	1	34	29 N.	19 E.	......	925	Jan. 15, 1916	2,035	2,040
......	Hill	......	19	25 N.	20 E.	......	......	......	1,925	......
......	......	......	?	19 N.	22 E.	......	......	......	2,550	......
Gahoma Oil	Crittenden	1	35	19 N.	23 E.	NE. c SW.	736	June, 1922	1,761	1,831
Adair O. & G.	Artie Brown	1	32	19 N.	25 E.	NE. c SE. NW.	......	June 1, 1919	1,395	1,430

* Many Osage leases are listed by legal description instead of name.

† Last entry in each line is quarter-section; C = center; c = corner.

	Kansas									
Elmerdale Oil	W. A. Sleigh	1	36	31 S.	2 E.	SW. c NW.			3,420	3,550
Hartman & Skaer & Derby Oil	Nibel	1	22	29 S.	3 E.	SE. c SE.		Nov., 1924	4,030	4,030
			7	22 S.	4 E.				3,355 (schist)	
Fancher *et al.*	U. S. Smith	1	1	23 S.	4 E.	NE. c SE. SW.			3,468	
Gypsy Oil	Shumway	27	11	26 S.	4 E.	NE. c SW. NE.	1,394	Dec. 8, 1919	2,695	2,715
Union Oil	Denny		12	26 S.	4 E.				2,805	
Empire G. & F.	E. C. Varner	31	17	28 S.	4 E.	SW. c NE. NE.	1,253	July 22, 1918	2,865	3,100
Gypsy Oil	Droll	1	2	7 S.	5 E.	SE. c SW. NE.	1,275	June 30, 1917	2,385	2,520
Prairie O. & G.	J. J. McLinden	1	25	20 S.	5 E.	NW. c SW. NE.			3,040	3,050
Roxana Pet.	Lilly	1	14	23 S.	5 E.	SW. c NE.	1,480		2,331	2,500
Dutton & Gillespie	Hassenthalter	1	15	23 S.	5 E.			Oct. 21, 1921	2,735	2,737
Roxana Pet.	Covey	1	26	23 S.	5 E.	C S. line NW.		Oct. 16, 1917	2,545	2,609
Federal Oil	Southworth	1	5	18 S.	6 E.	SE. c SE.			2,515	2,523
	Whitney	1	15	18 S.	6 E.				2,424	
	Case		19	18 S.	6 E.				Granite reported	
J. B. Markey	G. F. Collett	1	7	19 S.	6 E.	NE. c SE. NE.			2,596	2,612
O'Rourke *et al.*	C. Zumbrum	1	28	12 S.	7 E.	SW. c NE.		Early in 1917	1,805	1,895
Echo Oil	Whiting	1	24	15 S.	7 E.	NE. c SW.	1,384	Late in 1916	2,512	2,551
	Hiegle	1	11	16 S.	7 E.				1,900	
Empire G. & F.	Moffett	1	34	17 S.	7 E.		1,560	1917	2,506	2,608
	Anderson	1	4	18 S.	7 E.				2,110	
DeLaat & Shepard	Chase County Poor	1	34	19 S.	7 E.	SW. c SW.	1,203		1,805	2,501
Empire G. & F.	Kaufman	1	2	20 S.	7 E.	NW. c NE.	1,388	Feb. 8, 1917	1,890	3,055
	Prather	1	8	20 S.	7 E.				1,945	1,948
Empire G. & F.	James Edgar	1	35	27 S.	8 E.	SW. c NE. NE.			3,270?	3,855
Blue Vermillion O. & G.			20?	2 S.?	9 E.?				1,268	1,271
Blue Vermillion O. & G.	C. A. Harry		20	2 S.	9 E.				1,420	2,995
	Hooper	1	24	9 S.	9 E.				1,850	2,225
Parker O. & G.	Bardwell	2	26	10 S.	9 E.		1,003	1915	945	1,200
Parker O. & G.	Bardwell	1	27	10 S.	9 E.	SW. c NE.?	1,005?	1915	958	1,093
Empire G. & F.	G. A. Root	1	1	11 S.	9 E.	SW. c NE. or SW.	1,069	Early in 1917	1,169	2,000
			8	11 S.	9 E.	C N. ½ of sec.			Granite reported	
	Allen		24	19 S.	9 E.				3,610?	
Crawford & Jennings	Miller	1	12	10 S.	10 E.	SE. c SE.			2,215?	2,400?
Orlando Pet.	Breitkranz	2	4	24 S.	10 E.	NE. c SW. SW.			3,812	
			15	30 S.	10 E.	NW. c SW.	1,074		3,250	
Nemaha O. & G.			19	3 S.	11 E.				940?	2,650?
Empire G. & F.	Albert Rokes	1	34	6 S.	11 E.	C SW. NW.	1,450 ap.	Jan. 18, 1917	960	1,810
			34	2 S.	12 E.	NW.	1,150 ap.	1904	586	746
Wrightsman Pet.	Byers	1	26	25 S.	14 E.	NW. c SW. SE.		July 21, 1924	2,490	2,496
Aurora O. & G.			17	25 S.	15 E.	NW. c SW.			2,585	2,591
Elmhurst Inv.	Badger	1	4	15 S.	16 E.	SE. c NW. NW.			2,835	2,835

TABLE I—*Continued*

Company	Farm	No.	Section	Township	Range	Location*	Elevation (Feet)	Date Completed	Granite at (Feet)	Total Depth (Feet)
						Kansas				
....	....	......	20	30 S.	16 E.	....	....	....	2,312?	2,412
Equity O. & G.	....	......	29	26 S.	17 E.	....	....	....	2,405	....
Brown & Wolf	Miller	......	33	33 S.	17 E.	NE. c NW. NE.	720	....	2,155	2,160
C. O. Pingrey	Arnett	......	34	30 S.	18 E.	....	....	....	2,234	2,240
....	....	......	13	9 S.	19 E.	....	....	....	3,175?	....
....	....	......	......	17 S.	23 E.	....	....	Prior to 1893	2,100	2,500
....	....	......	25	26 S.	23 E.	NW.	....	....	1,826?	....
City of Columbus	....	......	13	33 S.	23 E.	....	....	....	1,761	....
						Missouri				
....	....	......	......	39 N.	31 W.	....	....	....	2,000	2,300
....	....	......	7	48 N.	32 W.	....	870	1886	2,348	2,401
D. A. Beamer	....	......	......	......	......	Barton County near Lamar	....	1911	1,850	1,880
Nevada O., G. & Asphalt	....	......	......	......	......	....	....	Prior to 1913	....	1,800
City of Carthage	....	......	......	......	......	....	....	Prior to 1894	1,750	2,005
						Nebraska				
Amerada Pet.	....	......	26	11 N.	12 E.	C NE. NE.	....	1924	1,826	....
Jim Hurst Co.	....	......	29	3 N.	12 E.	....	....	....	about 600	....
Jim Hurst Co.	....	......	6	2 N.	12 E.	....	....	....	about 600	....
....	....	......	25	1 N.	12 E.	....	1,225	....	552	652

* Last entry in each line is quarter-section; C = center; c = corner.

DISCUSSION

GEOLOGY OF THE STONEWALL QUADRANGLE, OKLAHOMA[1]

Certain features of the report by George D. Morgan on the geology of the Stonewall quadrangle should be brought to the attention of those interested in the stratigraphy of Oklahoma, especially as these features in no way detract from the accuracy in mapping or description of the beds outcropping in the Stonewall quadrangle. In the correlation table, Plate XXVII, page 157, the Boggy to Wetumka is made the approximate equivalent of the Marmaton; the Wewoka, of the Kansas City; Holdenville, of the Lansing; Seminole, of the Douglas; Francis to Vanoss, of the Shawnee and Wabaunsee; and the higher beds, of the Permian. The word "approximate" is used because Morgan does not show by the lines the exact correlation indicated above.

It has been commonly known among geologists working in central Oklahoma that the Seminole conglomerate is below the "Checkerboard lime," which in turn has a place somewhere in the upper half of the Marmaton. Furthermore, Morgan reports (p. 105) *Chonetes mesolobus* from the Holdenville. This fossil is a marker for the Des Moines group, that is, strata below the Kansas City formation.

On the geologic map of Oklahoma compiled by H. D. Miser in co-operation with the geologists of Oklahoma, the base of the Vamoosa formation is the approximate equivalent of the base of the Nelagony, and the Nelagony equals the Lansing, perhaps including basal Douglas. Assuming that the strike and thickness of the beds above the Nelagony and Vamoosa make no erratic changes, it is hard to conceive how beds younger than Neva can be represented in the Stonewall quadrangle, unless by overlap or unconformity. It is the belief of the writer that Asher will be found to be of lower Enid age, because of such overlap. This, however, is still a matter of conjecture.

FRANK C. GREENE

[1] Issued by Bureau of Geology, Norman, Oklahoma, for private circulation.

REVIEWS AND NEW PUBLICATIONS

Valuation of Oil and Gas Lands. By Robert Wesley Brown. New York: McGraw-Hill Book Co. Pp. 215, figs. 41, tables 21. Price $3.00.

In this book the author summarizes the things that determine values of oil and gas lands, discusses the factors that affect their significance, tells how they may be recognized, and gives methods for their application.

In chapter i, "The Nature and Determination of Value," the author discusses the various meanings of the term "value," and some factors related to it, and mentions a few occasions where its determination is of considerable importance. In chapter ii, "The Estimation of Oil Reserves, Producing Wells," there is a short discussion of the methods of statistical study, a few paragraphs on the characteristics of a producing well, and a detailed description of production-decline curves and their construction. Cumulative-production curves, comparative-production curves, and rate-of-production curves are also described. Chapter iii, "Estimation of Oil Reserves, New Locations and Undeveloped Acreage," calls attention to certain phases of geology which are important in connection with oil studies. This is made the basis for a classification of acreage, and is related to the well-spacing problem and to the drilling program.

Chapter iv, "Petroleum Prices," briefly describes the chemistry of petroleum and the refined products that may be derived from it. Relations between supply of petroleum and storage, production, and costs are pointed out, artificial factors of price regulation are mentioned, and there is a brief résumé of past prices for crude from the various oil fields. Some suggestions of future-price predictions are made. In chapter v, "The Value of Physical Equipment," both new and used equipment are discussed. In chapter vi, on "Costs," attention is called to many of the items that enter into the cost of oil production. Examples are taken from different fields in the United States. Chapter vii, on "Interest," discusses the subject and gives two tables which show how to apply discount factors to future income. Chapter viii, on "Depletion and Depreciation," gives various methods for computing these items, and a table is given showing a depletion schedule over a period of seven years. In chapter ix, "Methods of Valuation," the author compares five general methods of valuation and illustrates the application of each. In addition, there is a short paragraph on the valuation of royalties. Chapter x is given up to a discussion of "Valuation under the Federal Income Tax Laws." In chapter xi, "The Valuation of Gas Lands," the author applies these general principles to the valuation of gas lands, and contrasts this phase of the problem with that where oil is concerned. There is an Appendix which gives logarithmic co-ordinates of de-

cline curves from the *Oil and Gas Manual* of the U.S. Treasury Department, a table of depreciation rates from the same source, and six tables showing different interest rates applied under different conditions for various time periods. This is followed by a seven-page Index to the whole volume.

Aside from a few unimportant errors, the book is free from typographical slips and shows painstaking proof-reading. It is printed and bound in the excellent style common to McGraw-Hill publications.

There are several features of the book with which the reviewer takes exception. In chapter ii the author explains the use of co-ordinate paper in plotting curves. The reviewer feels that the use of logarithmic paper has resulted in many radical estimates, just because the estimator tried to use the straight-line position, but did not know how to locate it. If the same points are plotted from the unit position, the curve obtained can be extrapolated with little difficulty, and attempts to shift these known points into the straight-line position are not only needless but dangerous. Such a proceeding had better be left for one who not only thoroughly understands the basic principles on which logarithmic paper is ruled, but can construct the mathematical formula for that particular curve. Any decline curve is merely a careful approximation, and such attempts at refinement are like measuring a short distance in terms of thousandths of a yardstick which itself may be incorrect by a few hundredths. On the other hand, the reduction of irregularities by such methods as running averages and equal areas (see pp. 20, 21, and 22) is both useful and rapid in application.

The use of the term "sustained production," as defined on page 23, is questioned. Why not call it "new production"? This new production plus the older, more settled production results in a more or less sustained production or output.

Vacuum, water drive, and air pressure are referred to on pages 30 and 31 as employed to a very limited extent. This is true of water drive and air pressure, but is no longer true of vacuum, and where vacuum is applied in the later life of the well, the total additional recovery may equal 15 or 20 per cent of the total oil produced from the well. This is certainly true for the Appalachian district, the North Central fields, and the older production of Oklahoma.

The mathematical method of well-grouping was used in preparing some of the data for the first edition of the Treasury *Manual* in 1918, was used later in 1919 in the Valuation Section at Washington, and was then first used by Cutler in revising some of the *Manual* curves in 1920, and subsequently. The statement (p. 34) that Cutler was the first to use it is erroneous.

The statement of the Age-Size Law on page 40 is rather confusing and might be simplified somewhat. Figure 15 on page 41 brings out very clearly the relations between yearly decline and cumulative production, both in barrels and in percentage. The table on page 45 should be helpful in estimating the first year's production of a well from a record of a few months. Much of this chapter, about ten pages, is taken bodily from the *Oil and Gas Manual* of the Treasury Department. In chapter iii the author discusses the bearing of geological factors on oil accumulation and the estimation of reserves largely by quotations from publica-

tions of the U. S. Geological Survey, U. S. Bureau of Mines, A.I.M. & M.E., and other recognized sources. Briefer quotations with a careful digest of others' material might add greatly to the merit of this chapter. As it is, there is little new material here which constitutes a real contribution to the problem. The discussion of problems of well-spacing and a drilling program with reference to costs and ultimate recovery is very helpful and suggestive, but the chapter on petroleum prices leaves much to be desired, and the reader will find a much better treatment of this topic in Pogue's *The Economics of Petroleum*. The chapter on costs is good but is too brief. This topic is critical in valuation work, and the most careful analysis of it is essential to good work.

In the chapter on interest, pages 129–30, the author quotes J. R. Finley in a 1911 publication,[1] in which he advocates 5 per cent as a reasonable rate of interest. The valuation of iron mines in Michigan deals with a low risk factor. In this connection attention is called to some of Finley's statements in a later publication:

> The number of mining enterprises in this country that are rich enough to warrant an operating life of less than five years would probably constitute only a minute fraction of the industry, certainly not worth public attention. There are of course many mines in the country where the earnings on the capital invested are still handsome, say from 25 to 50 percent., but the largest mining enterprises are already far below that figure. In the case of the United States Steel Corporation the capital invested averaged before the war no less than $140 per ton of finished product sold each year, and the earnings only $8, or less than six percent. If money is worth five percent. interest, the shortest justifiable life of such an investment is more than 40 years. If the earnings on capital are ten percent. the shortest justifiable life will be fifteen years. It may be worth while to repeat for the sake of emphasis, that the shortest justifiable life is that which will merely return the capital with such interest as might be obtained merely by lending the money on good security. When we come to take account of the difficulty of guarding against chances of failure such as lie in the overestimate of the ore supply, underestimate of cost, unfavorable changes in price, or in absolute accidents, it seems venturesome to count on a return as low as ten percent. as a safe margin for investment. In order to justify it we should have to count on exterior factors such as a probability that the business would continue to expand indefinitely instead of being limited to an exhaustible deposit. Perhaps we shall not be far astray if we assert that the bulk of mining enterprises are based on a return of between 10 and 50 per cent on the capital required on the development, plant and working capital; that these returns vary according to the relative abundance of the materials dealt with, and that the higher returns are obtainable only upon bonanza deposits in which the mere discovery is a matter of capital importance.[2]

The hazards of oil properties certainly place them within this range of 10 to 50 per cent. The problem of properly evaluating an investment in a wasting enterprise, when the annual income represents a partial return of capital as well as interest, is commonly misunderstood, and the reader will find some excellent

[1] "Valuation of Iron Mines," *Trans. A.I.M.M.E.*, Vol. 45., p. 294.

[2] *The Cost of Mining*, p. 38. New York: McGraw-Hill Book Co., 1920.

discussions on this topic in Hoover's *Principles of Mining* and Finley's *Costs of Mining*, both of which contain some helpful tables. For a more complete set of interest and discount tables, the reader is referred to Hoskold's *Engineer's Valuing Assistant.* A discussion of annuities is scarcely appropriate in a treatise on oil-land valuation.

The chapter on depletion and depreciation has some excellent features, although this matter is more or less a problem of bookkeeping. The longer-lived oil companies carry reserve funds which are maintained for reinvestment, both in oil lands and in physical equipment. Depreciation with them is a matter of frequent inventory and actual valuation. The so-called practical oil man may err somewhat in his estimates of oil reserves, but this phase of the problem is largely a combination of efficient field operation and market conditions, and can be only approximated at best. The skilled operator gauges his depreciation according to individual lease conditions.

In several places in the book the author is prone to lay considerable emphasis on the obvious, such as "It requires technical training, knowledge of oil properties and sound judgment to make valuations successfully." Technical training may be obtained in the classroom, but the best training is experience, and the most efficient men today at valuing oil properties have spent years in the business, with little or perhaps no college or even high-school training.

Taken as a whole, the book has much excellent material in it, though much or most of it must be recognized as merely a compilation from various sources, and the extensive quotations from such publications as the *Oil and Gas Manual* of the Treasury Department, U. S. Bureau of Mines reports, etc., constitute a fifth of the text material.

JAS. H. HANCE

Further Considerations of Prospect for Oil in the Decatur Area. D. N. COLLINGWOOD. State Geological Survey of Illinois, Report of Revision No. 1, 1924.

Early in 1922, a well drilled near Decatur, Macon County, Illinois, found a showing of oil at a depth of about 2,100 feet. The discovery caused quite a rush of oil men, since it was about fifty miles from the nearest producing field, and it seemed possible that a new district of importance might be developed. Geologists were particularly interested, since it was well off the La Salle anticline, along which the truly important fields of Illinois are distributed. Further drilling failed to justify the sanguine hopes of a few, but the demonstrated occurrence of oil demanded geologic investigation, and this report, by Mr. Collingwood, of the Illinois Geological Survey, is the result.

The geologic structure of the region is shown by a structure contour map based upon No. 5 coal bed of the Decatur region as a datum. No statement is made in the report regarding the character, abundance, and reliability of the data upon which the structure contours were based, but the reader may infer that they were based almost entirely on drill records and particularly on the

records of holes drilled to prospect for coal. This conclusion is supported by the comparative complexity of structure where the greatest number of drill holes are situated. It seems very probable that intervening areas which, according to the map, have simple structure, actually have structures quite as complex as those areas where more data are available.

The study of structure of the deeper beds is complicated by convergence, which is compensated by means of a convergence sheet. The lines showing convergence appear on the structure-contour map, so that the manner in which the structure was determined can be understood. It is rather remarkable that convolutions in the convergence lines correspond quite closely, at least in some parts of the mapped area, to convolutions in the structure-contour lines. This suggests that either the comparatively slight folding of the strata resulted in marked thickening or thinning of certain of the beds, or else that the structure is more apparent than real and is due to change in thickness of strata and disconformable relations.

Four areas where structural conditions are at least moderately favorable for oil accumulation are mentioned. No closed anticlines are present, but plunging anticlines are well developed, and the wells which showed oil are situated on one of the plunging anticlines. The report very rationally recommends that drilling on plunging anticlines should be preceded by shallow tests to demonstrate the presence or absence of actual closure. An area not specifically mentioned in the report as favorable, but which may show promise, is in the central part of T. 15 N., R. 2 E., about six miles south of the Decatur region. In this area, the contour lines are very widely spaced, suggesting the possible existence of doming that might be revealed by carefully spaced shallow wells.

The oil, which is reported to be of excellent quality and to test 39.5° Baumé, was found in Silurian limestone directly below the Sweetland Creek shale. The limestone apparently was rendered porous during a period of emergence before the deposition of the shale. Other horizons which may possibly yield oil are, according to the report, the shallow sands of the Pennsylvanian and upper Mississippian, and a very fine-grained sandstone about 400 feet above the top of the Sweetland Creek shale. It is somewhat surprising to the reviewer that no mention is made of the Trenton as a possible oil-yielding horizon, particularly in view of the fact that it lies less than 3,000 feet below the surface and that one well in the Decatur area was drilled to it and had a showing of oil. Evidently the author considers Trenton possibilities here negligible as compared with those in the upper horizons. It is true that the Trenton in Illinois has not yielded a great volume of oil, but paying wells have been obtained from it, and certainly it must be considered a possible if not a probable paying horizon.

A feature of the bulletin that will meet the approval of both geologists and operators is an Appendix giving the records of a number of wells drilled in the Decatur area. This is particularly helpful since both the drillers' logs and the record compiled from a study of the cuttings are given for some of these wells. Readers who are not very familiar with the geography of Illinois would probably

approve the inclusion of an index map showing just where the area is situated, and inclusion of the county name in the title, which would permit them to locate the area without having recourse to a detailed study of the district or of the map.

K. C. HEALD

Estimation of Underground Oil Reserves by Oil-Well Production Curves. By WILLARD W. CUTLER, JR. *Bulletin No. 228,* Bureau of Mines, 1924. Pp. 114.

This publication is a valuable compilation by an ably equipped man who has spent much time in analyzing the merits of many methods of estimating underground oil reserves. The author begins by reviewing methods of estimating reserves now considered obsolete, a number of which still serve as checks or rough estimates against a more accurate calculation. In the second chapter he proceeds to the discussion of production-decline curves. A thorough explanation of the methods of plotting data to obtain the rate of production decline is followed by a prediction of the future yield for individual wells or properties. In the course of such work, a knowledge of the use of logarithmic, semi-logarithmic, and co-ordinate graph paper is need. Numerous diagrams and descriptions acquaint the layman or prospective appraiser with their application.

Chapter iii is by far the most important one, and is most voluminously treated. The feature to which the largest number of readers is likely to take exception is the author's partiality to certain methods of constructing average curves. Lewis and Beal's law of equal expectations is taken up at some length, which naturally should be the case, for up to the present time no better law applicable to estimation of reserves has been found. He adds a point heretofore omitted, namely, that the law does not apply to wells producing under hydrostatic pressure, as in the Tampico-Tuxpam district of Mexico. A short review of the age-size law of Johnson and Roth is made without describing it as in the case of other curves. This may be construed as indicating partiality, for in a compilation of this kind all methods should be completely described, and their disadvantages set forth. The author has apparently overlooked the merits of this principle. In the opinion of the reviewer, the age-size law is a refinement worth applying where data are available, although, as mentioned, records are usually lacking in needed detail to warrant its use. Consideration of the age of a well is undoubtedly more accurate than a complete disregard of this factor.

It is hardly possible in a review of this kind to analyze all the decline curves described. The family-curve method, the segmental-curve method, the mathematical method, and the appraisal-curve method are taken up in order. The author gives precedence to the family-curve method, which is the graphical procedure for the segmental method, and the limitations of the latter should therefore apply to the former as well. The reviewer considers the mathematical method better than the family-curve method in that it better lends itself to the weighing of the data. Its limitations are the same as those for the segmental- and family-curve methods. This is an excellent place to mention the misleading

nature of the name "appraisal-curve method." A more descriptive name might be the "scatter-diagram method." The author fully sets out the advantages and disadvantages of this method originated by Carl Beal.

The discussion of the average curves above is followed by that of methods of combining the information obtained therefrom into future-production curves, that is, a curve from which the ultimate or remaining yield can be read directly by using a known unit of production. A very useful auxiliary curve called the rate-of-production curve is next described. This curve is indispensable, especially in evaluating wells for discovery. The chapter closes with an analysis of the various refinements that should be considered whenever possible, such as spacing of wells, location on structure, porosity, etc.

The author is to be commended for the clear manner in which he explains all methods. The subject is one easily misunderstood, demanding just such clear and comprehensive treatment as has been accorded it by Mr. Cutler.

PAUL RUEDEMANN

TULSA, OKLAHOMA

Elements of Petroleum Geology. By FRANCIS M. VAN TUYL. Denver: The Petroleum Publishing Company of Colorado, 1924. Pp. 275, 34 figs.

This book is written primarily for the benefit of "laymen who are interested in petroleum geology, whether from the standpoint of intellectual development, the production of oil, the leasing of prospective oil lands, business relationships, or investments." Plainly, then, the geologist must not expect to find in it contributions to existing knowledge regarding the occurrence of oil, since the presentation of such data, with essential discussion of theory, would undoubtedly puzzle the readers the book is especially designed to reach.

The futility of attempting to convey information regarding a refinement or specialized aspect of a subject to an audience unfamiliar with the fundamentals was evidently realized by the author, since he begins his book with discussions of general, historical, and structural geology. The reviewer, after laboring through several months to convey certain of the simpler facts of elementary geology to a group of college students, rather marvels at Dr. Van Tuyl's optimism in his apparent belief that enough can be packed into thirty-one pages to enable a man to understand many of the principles of petroleum geology, but this meager space is unquestionably used quite effectively.

The "elements" referred to in the title, exclusive of those pertaining to general geology, include composition of oil and gas, their origin and migration, the types of reservoirs in which they are found, structural conditions in oil and gas fields, and methods of prospecting for these fields. Some idea of all these things will undoubtedly be gained by the reader, who may in this way be started on the way to understanding discussions of oil-field conditions and of factors bearing on the possible occurrence of oil in different regions. The geologist with even an elementary acquaintance with oil and its occurrence will gain nothing from it.

Twenty-four pages are devoted to description of the oil and gas fields of North America. These, like the preceding pages, may be of value to one who has no previous knowledge of the occurrence of oil. The man who is familiar with these fields will be more impressed by the inadequacy of the descriptions than by their helpfulness. It seems apparent that these descriptions were hastily compiled without great effort to acquire the essential facts. A description of an oil field should contain enough historical data to permit the reader to learn when the field was discovered and what its comparative importance is and has been, what type of oil it yields, the character and stratigraphic position of the reservoir bed or beds, the depth of drilling, and the structural conditions which, in general, govern the occurrence. Some of the descriptions in this chapter contain all these essentials. More of them do not. The positions of the fields are shown on a map of the United States which, unfortunately, is a copy of an obsolete and inaccurate map published many years ago by the U. S. Geological Survey. Some corrections seem to have been made, but apparently these are all additions, for the map shows fields in the Sacramento Valley of California, along the coast of Oregon, in Nevada, the Dakotas, Iowa, and in other states where showings of oil or gas have been reported but no fields ever developed.

Finally, there are chapters on leasing oil and gas lands, on oil-field development, and on oil speculation which, like those on geology, will doubtless be informative to the man unfamiliar with the subjects.

The most valuable part of the book, in the opinion of the reviewer, is the Appendix, which is a splendid collection of lease forms, royalty-purchase forms, and other types of oil-field contracts and agreements. This compilation, which is the work of A. W. Heinemann, secretary of the Producers and Refiners Corporation, is by far the most complete collection of such forms that the reviewer is familiar with, and should justify any oil geologist in giving library space to this book.

K. C. Heald

Yale University

Oil and Gas Field of the Lost Soldier–Ferris District, Wyoming. By A. E. Fath and G. F. Moulton. *Bull. 756, U. S. Geological Survey,* 1924.

The appearance of a government publication on the Lost Soldier district, Wyoming, has been noted with much satisfaction by all Rocky Mountain geologists and oil and gas operators. During the eight years in which developments in the Lost Soldier district have been under way, oil, gas, or both, have been discovered in six separate folds out of nine well-known domes or anticlines of the district, giving it an important place among the prospective and producing areas of Wyoming. The large areal extent of the district and the rather difficult and hidden structural relationships between the various anticlines and synclines make it especially desirable to have a large general presentation of structural conditions in order to appreciate the value of each portion of the district in relation to the whole, or any other part. *Bulletin 756* is, therefore, welcomed by all.

In attempting to review this important paper, the writer wishes to present briefly an outline of the contents of the bulletin without trying to cover the subject-matter in detail. Attention will be called to particular features of the work, and especially those which seem new or unusual. Finally, a discussion of certain conclusions reached by the authors of the bulletin will be undertaken, and it is hoped that no offense will be taken at any exceptions or criticisms offered by the writer, who wishes thereby to assist in reaching a clearer understanding of the main problems, and who will appreciate discussions by other members.

The paper begins with a brief introduction and summary of geologic results, and a review of previous geologic investigations in the district. Then follow short chapters on geography, topography, water supply, vegetation, culture, and markets for oil and gas. An index map, showing the general location of the district, and several good photographs are helpful features of the introductory presentation. Then follow the more important chapters on the stratigraphy and structure, with geologic and structure maps, a generalized section in tabular form, and a chart giving the succession of formations and approximate correlations for other fields of Wyoming, with productive horizons suitably indicated for each field. The subject-matter of the bulletin is concluded with tables of petroleum analyses, and a short chapter on porosity of sands.

The parts of the bulletin most frequently referred to by those operating in the district are the stratigraphic section on pages 10 and 11, and the structure map, Plate I, which indicates the location of the structures and development areas. The section is capable of careful measurement, and should be presented in as accurate a form as possible, since all depth estimates are based on it, and interpretations of logs of wells are dependent on its subject-matter. Structural representations, on the other hand, are interpretations, and may differ considerably in accordance with the individual views and practice of different geologists. As given in the bulletin, thickness data for the different formations show wide variations in some cases. In the lower portion of the Colorado group, the maximum and minimum thickness figures seem to be too far apart, and should be revised. The interval from the top of the Frontier to the top of the Cloverly formation, as determined from well logs in the different fields of the district, ranges from 1,175 to 1,325 feet, showing the thickness factor to be much more constant for this part of the section than the published data would indicate. Similarly, the thickness of the Mesaverde should be more definitely determined, though it is less important because of its high position in the section.

As shown on Plate I, the Lost Soldier–Ferris district includes nine domes and anticlinal folds, with separating synclines or saddles along the anticlinal axes. The map also shows the distribution of formations at many points, showing many disconnected outcrops of Cretaceous rocks with the intervening areas occupied by Quaternary deposits. Interpretation of structural features under these conditions is rendered difficult, and in some parts of the district, widely

different views of the probable structural conditions have been held by geologists who have been charged with a study of their prospective possibilities. A large number of dry holes scattered over the district testify of the incorrectness of many of these interpretations, and in other places credit is due for successful deductions and the finding of commercial oil and gas pools. The authors of the bulletin have presented several new departures to which the writer wishes to call attention.

One of the most difficult geological problems of the district centers about the area known as Sherrard dome. The interpretation by Fath and Moulton places the top of the structure more than a mile northeast of the nearest dry hole, and more than 2 miles from the top as recently determined by F. A. Craise, of Denver. This structure is now undergoing its fifth test, having been held by four different operating companies at various times, and if the present operation should prove a failure, a test may be made in the locality which the authors designate as the top of the dome. The uncertainty is due to lack of exposures of the Cretaceous formations over a large area, and the necessity of making projections from the distant rim rocks. Most geologists have placed the top closer to the western exposures, because the dips are steepest on that side of the structure, and in general the axes of unsymmetrical folds of this kind occur that way.

Another unusual feature of the map is the interpretation of structure immediately north of Bell Springs fault. In the area immediately west of Bell Springs, the Niobrara and Carlile shales are more extensively exposed than indicated on the map, and a low escarpment of Niobrara sandy beds in the southern parts of sections 7 and 8, T. 23 N., R. 88 W., shows southeast, south, and southwest dips, indicating the southern closure of a dome structure which is now generally called Bell Springs dome. It appears, therefore, that a dome structure trending northward, parallel to the Mesaverde escarpment on the west, and crossed by Separation Creek north of its high point, occupies the area shown to be on the west flank of Separation Flats anticline. The discovery of a commercial gas pool by the Kasoming Oil Company and Producers and Refiners Corporation, on Section 6, T. 23 N., R. 88 W., lends strength to this interpretation. And in accord with this view, a syncline must occupy the western part of the area indicated as the top of Separation Flats anticline, separating the Bell Springs dome from the north end of the Rawlins uplift.

Another feature of the map worthy of special notice is the representation of a structural high along the axis of the O'Brien Springs anticline, south of Table Hills. The strike lines on the beds north and south of the axis of this fold converge eastward, indicating that the anticline plunges in that direction. No evidence is given on the map of any strike lines converging toward the west, and the question naturally arises as to the basis for showing any closure. In the text (p. 50) the authors say that "whether or not the anticline rises toward the west and flattens out or whether it becomes more closely folded and carries a local 'high' or dome is obviously uncertain." "The configuration of the anticline as

represented by contours on the map is based entirely on the extrapolation of dips." But the method of extrapolation used to obtain a closed contour from "open" dips is not obvious to the writer. Reasoning from the steady westward rise of the synclines to the north and south of the anticlinal axis, it would seem that the anticline probably also rises in that direction, and that if there is any "high" or dome, it must exist west of the exposed portion of the Table Hills syncline, south of the Stone ranch.

The authors' views on the age and relation of the Rawlins uplift with respect to the so-called minor folds of the Lost Soldier–Ferris district are also worthy of special notice. In their summary of geologic results (p. 2) we read:

> The district as a whole is the modified north end of the Rawlins uplift, a regional feature of major magnitude. The investigation has shown that most of the minor domes and anticlines that control the oil and gas accumulations in this district were formed at a much later date than the major Rawlins uplift, on which they are superimposed. The Rawlins uplift is of pre-Wasatch age, but the minor folds are of post-Wasatch age, and perhaps may be as recent as post-Oligocene.

In looking through the bulletin for the basis on which these conclusions rest, we find on page 30 a chapter on regional features, in which general relationships are discussed. No reason is given there, so far as the writer has observed, for regarding the "minor folds" as a modification of the northern end of the Rawlins uplift. It is also not clear how the Sherrard, Little Lost Soldier, and Wertz domes are included with the other "minor folds" in general alignment "transverse to the major axis of the Rawlins uplift." These structures, together with Bell Springs dome, trend north-northwest, and appear to have been the result of the same set of forces which produced the Rawlins uplift, if alignment is used to indicate related folds. If the Rawlins Hills are viewed as a faulted anticline, which they seem to be (disregarding their greater height, which does not seem to change their essential relations, since the "minor folds" show considerable differences in respect to their comparative heights), it seems quite natural to regard the Rawlins uplift simply as one of the folds of the district. Both the north and south ends of this uplift are anticlinal in character, and to the south and east two anticlinal folds, the Eight Mile–Miller Hill fold and Grenville–Fort Steele anticline, lead directly from the Rawlins uplift without serious interruption. Viewed in this way, the Rawlins Hills are the central and highest portion of a long line of folding which terminates in the Little Lost Soldier dome on the extreme north end of the disturbance.

In another publication by the senior author of the bulletin, the relative ages of the major and minor folding in the district have been discussed, and reference to that paper is made on page 30. The writer has carefully read Fath's arguments, which lay great stress on the significance of alignment of folds with the Ferris-Seminoe line of deformation, and conclude that the minor folds are the same in age as that deformation, which is said to be much later than the Rawlins uplift disturbance. But if part of the folds are aligned with the Rawlins

Hills, as suggested above, the argument loses much of its force, and the relative ages of the minor and major folding must be established in some other way. Disturbances in post-Wasatch time, which appear to have affected the Ferris-Seminoe element without noticeably affecting the Rawlins uplift, could hardly be accepted as proof that the major uplifts were formed at different times, and that the so-called minor folds are the result of the latest movements altogether. But the authors do not present the facts regarding the attitude of the Wasatch beds in relation to the Cretaceous formations to bear out their statements, and the writer does not know of stratigraphical relationships which support their hypothesis. Max Ball has written on the subject of the "Relative Ages of Major and Minor Folding and Oil Accumulation in Wyoming,"[1] and he concluded that "nearly all the minor folds of Wyoming were formed during the period of formation of the major uplifts."

The point regarding the possibility of the more recent age of the minor folds is especially interesting because of its bearing on the subject of oil and gas accumulation. If the folds which are being exploited for oil and gas are much younger than the major folds, it is contended by the authors of the bulletin that "the oil and gas that is present in this district today for the use of man must therefore be merely a remnant of all the oil derived from the mother material which the rocks of this region originally obtained" (p. 31). On the other hand, if the minor and major folds are the result of the same deformative movements, then Ball contends that "the minor folds received their relative shares of the oil formed, the amount in each case depending on the richness of the source, the drainage area, and circulation conditions. If some Wyoming folds have proved disappointing, other reasons must be sought than the relative ages of folding and oil migration." It is interesting to note that out of nine known structures in the district, commercial production has so far been obtained on six, and development is proceeding on one of the remaining non-producing structures. It seems possible, therefore, that when properly located wells are drilled on the remaining folds, production may be found on them also. It follows, then, that early drainage did not affect accumulations adversely in this district, which might be a point in favor of the contemporaneous origin of the major and minor folds. However, if there is stratigraphic evidence to show a great difference in the age of the major and minor folding of this district, the writer would be very glad to have it presented in order to clarify our present notions on this interesting subject of oil migration in relation to periods of folding, at least as far as this district is concerned.

The writer does not find a discussion of the Bell Springs fault in the bulletin, but feels that it is of very great importance in a consideration of the possible oil and gas accumulations within the district. If the Rawlins uplift is an anticline related in age and origin to the other folds of the district, the possibility of finding oil and gas in faulted half-domes along the west side of the fault becomes

[1] This *Bulletin*, Vol. 5 (1921), p. 49.

an interesting subject for study. The fact that the fault line is confined closely to the Rawlins fold, being a normal strike fault along its west limb, and curving somewhat around its northern extremity, indicates that it is connected closely with the origin of the uplift. Otherwise we should expect other faults of similar magnitude in other parts of the district as well. At a point a few miles south of Bell Springs, the fault bisects a fold, and Cretaceous beds lie in contact with the early Paleozoics, but the latter show a fold which is similar, though of gentler character, in a position adjacent to the half-dome in the Cretaceous beds, suggesting that they were formed at the same time, and were parts of the same fold prior to the faulting. It seems probable that after the folding had reached a certain stage, the vertical component of the stresses became so great that faulting took place, and the flank of the fold was the weakened portion along which the beds were ruptured. The faulted minor fold here referred to is undoubtedly of the same age and origin as the other minor folds of the district, and this situation suggests that the Rawlins Hills may have suffered considerable uplift during the later stages of the deformation which produced these folds.

In concluding, the writer cannot resist expressing the feeling that much has been found out by the study and developments within the district since the field work on which the bulletin is based was done, and that there still remains much to be learned. The U. S. Geological Survey has great facilities for attacking just such problems, and it would be a great aid to further developments in the district to continue the work begun by Fath and Moulton, especially in the southern half of the district, and southward beyond the Rawlins uplift. Regional studies should throw light upon the difficult relationships between major and minor folding, and eventually the true succession of events might be established.

F. F. Hintze

Denver, Colorado
January 29, 1925

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[1] Published by permission of acting director, U. S. Geological Survey.

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Myers, Julian Q., 116 E. King St., Tulsa, Okla.

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Noble, Earl B., Union Oil Co., Maricopa, Calif.
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O'Brien, Shamus, Florence, Kan.
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Osborne, Robert R., 40 E. Fourteenth St., Tulsa, Okla.
Ott, Emil, 237 N. Magdalen St., San Angelo, Tex.
Owen, Herman J., Ohio Oil Co., Findlay, Ohio.
Oyster, Frank A., Box 392, Independence, Kan.

Packard, Sidney A., care of American Consul, Maracaibo, Venezuela, S. A.
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Putnam, Laurence G., East Coast Oil Co., Apartado 125, Tampico, Tamaulipas, Mexico.

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Reed, Warren B., Morgan City, La.
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Sir Thomas H. Holland, K.C.S.I., K.C.I.E., F.R.S., has been elected president, and The Rt. Hon. Viscount Cowdray of Cowdray, G.C.V.O., Sir John Cargill, Bart., Mr. Alfred C. Adams, Mr. Alexander Duckham, F.C.S., Mr. Arthur W. Eastlake, M.I.Min.E., A.M.I.Mech.E., and Mr. Robert Redwood, F.C.S., have been elected vice-presidents of the Institution of Petroleum Technologists for the ensuing year.

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Commitee has approved for publication the names of the following applicants for membership in the Association. This publication does not constitute an election, but places the names before the membership at large. In case any member has information bearing on the qualifications of these applicants, please send it promptly to Charles E. Decker, Norman, Oklahoma.

(Names of sponsors are placed beneath the name of each applicant.)

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NOTE

After the galley proof of the article by W. H. Bradley, on pages 247–62 of this issue, had been returned to the editor of the A.A.P.G., the writer became acquainted with a manuscript of Dr. David White's which discusses in some detail the origin of carbonaceous deposits. This manuscript was submitted for publication several months ago but, since it is to be printed in book form, has not yet appeared. In that manuscript, Dr. White discusses the sapropelic deposits both recent and fossil and presents his conclusions regarding the origin of the Green River oil shale, a subject which has been of considerable interest to him for some years. His conclusions are almost identical with those which the present writer has arrived at by entirely independent study and presented for the first time in his article appearing in this issue of the *Bulletin*.

Some of the evidence presented by Dr. White is wholly new to the writer and some of the evidence presented at this time by the writer is equally new to Dr. White, but both lines of evidence converge, strongly supporting the common conclusion regarding the origin of the Green River oil shale.

The writer takes this opportunity to make it clear that Dr. White reached his conclusions regarding the origin of the Green River oil shale and submitted his manuscript which set them forth previously to the preparation of the writer's present paper, which only by reason of its more rapid progress in publication is appearing first. The writer also regards the convergence of the two lines of reasoning by independent workers as additional proof that the conclusions reached are essentially correct.

W. H. Bradley

April 2, 1925

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

EARL A. TRAGER, formerly in charge of the geological work of the Mexican branch of the Marland Oil Company, has been transferred to Ponca City, where he will have direction of the geological work of the Research Department recently organized there.

RAYMOND C. MOORE has recently lectured on his exploration and geologic studies in the Grand Canyon of the Colorado River, at the universities of Chicago, Wisconsin, Illinois, and Missouri.

CARLTON MEREDITH, of Meredith and Reeves, consulting geologists, of Dallas, Texas, recently made a professional trip into northeastern Texas and northwestern Louisiana.

ROBERT R. THOMPSON, geologist with the Texas and Pacific Coal and Oil Company at Thurber, Texas, spent several days at Shreveport, Louisiana, in February, in the interest of his company.

W. E. HOPPER, Southwestern Gas and Electric Building, Shreveport, Louisiana, was engaged in consulting work in March in Crockett, Terrell, and Pecos counties, Texas.

E. H. SELLARDS, of the Bureau of Economic Geology and Technology of the state of Texas, is on leave of absence for work in Mexico.

H. K. SHEARER, of the geological department of the Standard Oil Company of Louisiana at Shreveport, was recently occupied in field work in the coastal plain of Alabama.

N. B. WINTER, in charge of the geological office of the Atlantic Oil Producing Company at Shreveport, Louisiana, made a business trip to Dallas in March.

A. F. CRIDER, chief geologist for the Dixie Oil Company at Shreveport, Louisiana, visited the San Antonio, Texas, office of the company several days in the latter part of February.

W. C. SPOONER, Ardis Building, Shreveport, Louisiana, has been carrying on geological investigations in wildcat territory in southern Arkansas.

After temporary inactivity, the SOUTHERN OKLAHOMA GEOLOGICAL SOCIETY has been reorganized and is now holding regular meetings on the third Tuesday of each month. The officers for 1925 are: president, C. E. CLOWE, consulting geologist; vice-president, GEORGE BURTON, geologist for the Humble Oil and Refining Company; secretary-treasurer, J. T. RICHARDS, resident geologist for

the Gypsy Oil Company. Visiting geologists are cordially invited to any of the meetings of the Society.

H. C. George, who was in charge of the Bureau of Mines at Ardmore, Oklahoma, has accepted a position at the head of a new School of Petroleum Engineering at the University of Oklahoma. Mr. George has already secured a great deal of equipment for the course, and the Junior work in this department is being taken by a large number of students.

N. W. Bass, of the U. S. Geological Survey, who is working on Kansas oil problems in co-operation with the State Geological Survey, has completed a preliminary report on Hamilton County prospects, in the extreme western part of the state.

R. M. Gawthrop, formerly chief geologist of the Transcontinental Oil Company, is now chief geologist of the Prairie Oil and Gas Company, with headquarters in Independence, Kansas.

H. S. Gale is in charge of the geological work for the Gypsy Oil Company (Gulf Oil Corporation) in California, with headquarters in Los Angeles.

William J. Willard, of Tulsa, is in Trinidad for the Barber Asphalt Co.

Jon A. Udden is geologist for the Tex-Mex Oil Company in Tulsa.

Santiago Aguerrevere, geologist for the Doherty interests, has returned to California after a year's absence in Mexico.

C. E. Dobbin is on a five months' furlough from the U. S. Geological Survey for work in Panama. He will be near Garachine, south of San Miguel Bay, in the southern part of the republic.

W. W. Rubey, who has lately been at work for the U. S. Geological Survey in the Black Hills, has been acting chief of the Fuel Section during the absence of W. Taylor Thom, Jr., on field work in the mid-continent.

Philip S. Schoeneck was married January 10 at Cleveland, Ohio, to Miss Marcia Snell. Their future home is to be at Billings, Montana.

Donald D. Hughes, geologist for the Marland Oil Company of California, with headquarters in San Francisco, is spending some time in New York on business.

M. N. Bramlette, of the U. S. Geological Survey, who has recently been engaged in graduate studies at Yale University, has gone to Ecuador, S. A., for the Gulf Oil Corporation.

J. Brian Eby resigned from the U. S. Geological Survey February 28 to accept a position with the Roxana Petroleum Corporation. He will be located at San Angelo, Texas.

A. F. Melcher has resigned from the U. S. Geological Survey to undertake work for the Marland Refining Company at Ponca City, Oklahoma.

C. A. P. Southwell, government geologist, of Trinidad, British West Indies, has been visiting in Tulsa for several weeks.

Ichizo Ohmura, of the Nippon Oil Company Limited, Marunouchi, Tokio, Japan, will spend the next ten months touring Europe. Mr. Ohmura is one of the Japanese subscribers to the *Bulletin*.

J. Y. Snyder, of Shreveport, Louisiana, has recovered from an attack of acute appendicitis for which he underwent an operation.

Roy Holloman has resigned from his geological work with the Ohio Oil Company at Shreveport, Louisiana, and is now making his headquarters at Denver, Colorado, where he hopes to improve his health.

L. J. Pepperberg, of Dallas, Texas, spent a few days recently in the Shreveport, Louisiana, district in the interests of clients.

Wesley G. Gish, formerly with the White Eagle Oil and Refining Company at Wichita, has married and moved to Tulsa, where he is now chief geologist for the Sinclair Oil Company.

H. R. Shidel and family recently moved from Wichita to Coffeyville, where he has accepted a position with the Oil Country Specialty Manufacturing Company. Mr. Shidel's interest in Oil Country's specialties will take him to various parts of the Mid-Continent field. You may see him anywhere 'most any time.

J. Elmer Thomas was recently in Wichita in connection with one of his business visits to his field office at Independence.

E. W. Scudder, who is actively in charge of the Gypsy Company's work in Kansas, is going to California next week for the improvement of Mrs. Scudder's health.

H. E. Crum and E. L. Bradley, of Colorado Springs, visited the meeting of the Kansas Geological Society at Wichita, January 17.

The Shreveport Geological Society holds a weekly luncheon meeting every Monday noon at the Washington Hotel, Shreveport, Louisiana, in addition to its monthly program meetings and the Howe lecture course at the Shreve Memorial.

H. W. Bell, supervisor of the Minerals Division of the Louisiana State Conservation Commission at Shreveport, Louisiana, is conducting laboratory tests on cement accelerators with variable factors of time and pressure.

J. Y. Snyder, capitalist and geologist, City Bank Building, Shreveport, Louisiana, is a vice-president and director of the reorganized Exchange National Bank of Shreveport.

E. L. Estabrook, chief petroleum engineer of the Midwest Refining Company at Casper, Wyoming, addressed the students in petroleum engineering at the University of Oklahoma, February 17, on the subject, "The Salt Creek Oil Field and Its Development." Other recent speakers have been C. W. Tomlinson, Ardmore, Oklahoma, on "Well Completions"; Frank Edson, Norman, Oklahoma, on "Diamond Drilling for Oil"; and C. O. Rison, U. S. Bureau of Mines, Muskogee, Oklahoma, on "Control of Wild and Burning Oil and Gas Wells."

J. B. Burnett, formerly in charge of the geological explorations of the Mexican Eagle Petroleum Company, Ltd., in Southern Mexico, and recently appointed assistant chief geologist of the combined Eagle and Corona geological departments at Tampico, has resigned the latter place and has accepted the position of chief geologist for the Lago Petroleum Corporation of New York and Maracaibo, Venezuela.

On December 19, C. E. Decker installed a chapter of Sigma Gamma Epsilon at the Mackay School of Mines, Reno, Nevada. He also visited the men of the chapters at the University of Utah and University of California, and while on his western trip had an opportunity to visit the Bingham Canyon copper deposit and the Comstock lode at Virginia City.

At the annual meeting of the Association of American State Geologists, held in Ithaca, New York, December 29 to 31, the following officers were elected for 1925: president, Wilbur A. Nelson, state geologist of Tennessee; secretary, M. M. Leighton, state geologist of Illinois; member of executive committee, E. W. Mathews, state geologist of Maryland. The Association voted to send a memorial to the President of the United States requesting a liberal support to scientific work. The memorial was presented in person by the new president of the Association, and was favorably received.

H. L. Hummel has been appointed chief geologist of White Eagle Oil Company, with headquarters in Wichita, Kansas. Mr. Hummel has been succeeded as district geologist in the Okmulgee district by Hy Daniels, formerly with the Producers and Refiners Company.

R. E. Witly succeeds C. R. Parker as assistant geologist in Okmulgee district for White Eagle Oil Company. Mr. Parker resigned to form a partnership with his brother in the contracting end of the oil business.

A. W. Duston has deserted the rank of consulting geologists and accepted a position as chief geologist for the Independent Oil and Gas Company of Okmulgee, Oklahoma.

Ray P. Walters, geologist for the Româno Americana, has been in Roumania since April, 1924, his present address being 126 Calea Victoriei, Bucharest. He has been making special studies of the salt deposits.

Alexander Deussen, Houston, Texas, was recently elected vice-president of the Marland Oil Company of Texas, and placed in charge of the company's activities in the Gulf Coastal Plain of Texas and Louisiana.

Dave Donoghue, consulting geologist at Houston, Texas, has been retained by the Marland Oil Company of Texas.

Wallace E. Pratt, who has served the Humble Oil and Refining Company in the capacity of chief geologist since 1918, was elected to the Board of Directors at the annual meeting of the stockholders at Houston, Texas, on February 16.

D. J. Edson, who has been acting as division geologist of the Humble Oil and Refining Company, with headquarters at Corsicana, Texas, for the past

five years, has resigned to enter the producing business on his own account. He will continue his residence at Corsicana as president and general manager of the Edson Petroleum Company, operating in Texas and adjacent states.

C. F. Bowen, chief geologist of the Standard Oil Company of New Jersey, with headquarters at New York City, spent several weeks inspecting producing fields in Texas and Mexico during the months of January and February.

Raymond Leibensperger, chief geologist, Compania Transcontinental de Petroleo, S. A., Tampico, Tamaulipas, Mexico, made a short business trip to Houston and San Antonio, Texas, in the early part of February.

A. E. Fath, geologist for the Vacuum Oil Company, New York City, has been in Texas for the past several months.

J. Elmer Thomas, consulting geologist, Chicago, Illinois, spent a few days in Houston during the month of February.

The Houston Geological Society, Houston, Texas, held a dance Friday evening, January 23, in the rooms of the University Club, which was an unqualified success. About sixty couples were in attendance. Dilworth Hager was chargé d' affaires, and President John Suman called the Paul Jones's.

The prairies of the Gulf Coastal Plain of Texas and Louisiana have become thickly dotted with the tents of torsion-balance operators, and pockmarked with the craters left by the seismic exploration parties. The local residents, astounded beyond comprehension by the antics of the torsion-balance men and the noise of the seismic work in the initial stages of this type of exploration a year or so ago, have become quite nonchalant now that the novelty has failed, and refer to the torsion-balance men familiarly as the "picture men" and to the seismic parties as the "dynamiters." A half-dozen of the larger operators of the Gulf Coast are employing these devices for detecting buried geologic structures, and the practice promises to become general. So far, nearly all field parties are made up of German or European experts, whose work is shrouded in mystery against all but their immediate employers. To date, torsion-balance operation is accredited with the discovery of a single new salt dome, the exploration having been carried out by the Rycade Oil Corporation, of which E. DeGolyer is president, Donald Barton chief geologist, and Robert Goodrich field geologist for the area in which the new dome was found. The seismic apparatus in the hands of the Gulf Production Company has already registered a notable success in the clean-cut discovery of two hitherto unsuspected salt domes in Fort Bend County, Texas. This work was carried out by the German experts of Baron Minthrop, under the supervision of L. P. Garrett, chief geologist, and W. F. Henniger, division geologist, of the Gulf Production Company.

R. E. Rettger, formerly assistant professor of geology at Cornell University, has joined the geological department of the Sun Oil Company at Dallas to take charge of subsurface work.

L. W. Storm, Thomas H. Kernan, and David B. Miller have recently joined the geological department of the Sun Oil Company at Dallas.

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